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# The Economics of Soil Degradation: An Illustration of the Change in Productivity Approach to Valuation in Mali and Malaŵi

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IIED
INTERNATIONAL
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# THE ECONOMICS OF SOIL DEGRADATION:

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# 1 INTRODUCTION

Soil is an essential input to farming. And yet agricultural land use often results in the degradation of natural soil fertility and reduced productivity. Soil degradation under farming also inflicts off-site costs, through the processes of erosion, sedimentation and leaching. Productivity losses and negative external impacts resulting from soil degradation are part of the social cost of agricultural production. However, these costs are often neglected by farmers and public planners. Part of the reason is that the negative consequences of soil degradation are usually unintended, often indirect or diffuse, and may be perceptible only over long periods of time. A more fundamental cause is that these costs are not fully reflected in market prices of agricultural inputs and outputs, and are therefore easily neglected in public and private decision-making.

Land users ultimately determine the rate at which soil resources are degraded through their choice of land use and production technology -- eg. their selection of logging and mining practices, crops and farm machinery, animal stocking density and rotations. Governments influence these choices through a range of economic incentives, laws and regulations, infrastructure and institutional arrangements -- from the location of public roads and dam sites, to imposition of agricultural taxes and subsidies, or regulation of land sales and leasing.

Current rates of soil degradation thus reflect both public and private choices, but they almost always exceed the rate that would be selected by an objective social planner, due to market and policy failures which mask the full cost of degradation to society. An important task for policy analysts and decision-makers is to identify the underlying causes of excessive soil degradation, to evaluate their economic significance, and to create incentives for less destructive land use practices. Appropriate policies can help by making the full costs and benefits of alternative land use practices more apparent to land users.

This paper begins by reviewing the basic concepts and techniques used in economic analysis of soil degradation, with selected examples from a range of countries. In Chapter 2, soil degradation is described in terms of physical phenomena. The impact of soil degradation on agriculture is discussed in terms of productivity, farmer response and technological change. Alternative, formal economic models of farmer decision-making with respect to soil degradation are briefly described. The chapter concludes with a review of the various market failures and policy distortions which often underlie excessive soil degradation. Chapter 3 goes on to describe a range of techniques for assessing the economic impact of soil degradation in monetary terms. The focus throughout is on agricultural land use and the depletion of soil fertility under cultivation of rain-fed field crops. Most of the arguments apply to other forms of land use as well, such as animal husbandry and forestry, although the specific processes of degradation and conservation will differ.

Chapters 4 and 5 present results from recent case studies of the on-site economic cost of soil erosion on farm land in two African countries: Mali and Malawi. These studies illustrate the technical problems that arise in the valuation of soil degradation, practical methods of overcoming these difficulties and some implications of valuation for agricultural policy. Finally, Chapter 6 reviews the main methodological difficulties and research priorities for economic analysis of soil degradation in agriculture. Data and methods used in the case studies are presented in a series of technical annexes.

# 2 SOIL DEGRADATION AND AGRICULTURE

## 2.1 Soil Fertility and Soil Degradation

Soil fertility is a function of many physical, chemical and biological properties which, together with climate and other factors, determine the suitability and potential productivity of land for agricultural uses. The essential attributes of natural fertility include soil structure and rooting depth, organic matter and trace nutrient content, plant-available water reserves and soil biology (Lal, Hall and Miller 1989).[1]

Soil degradation is not always the result of human activity. Soils are both created and destroyed through natural processes; they build up from alluvial deposits, weathered rock and accumulated organic matter, and are both augmented and protected by natural vegetation. Natural soil degradation results from geologic erosion, ie. the destructive effects of exposure to sun, wind and rain. From a human perspective, these natural processes tend to occur slowly, although occasional sudden landslides can have catastrophic consequences.

Human activity typically accelerates natural soil degradation. The impact of human land use arises primarily from soil disturbance, for example through clearing and tillage, which remove protective natural plant cover and expose the soil surface to harsh climatic influences. The result is soil compaction, reduced water infiltration and moisture holding capacity, increased run-off and erosion, and selective loss of nutrients and organic matter. Although the impact of soil disturbance will vary with scale and timing, and with soil depth, the inevitable effect is a relatively rapid depletion of natural soil fertility.

Soil degradation includes both on-site deterioration in soil quality, as well as the physical removal of soil by wind and rain, i.e. soil erosion. Erosion is expressed in terms of the loss of soil mass or depth per unit area and per unit of time (eg. tonnes/ha/year, cm/ha/year). Soil disturbance related to human land use generally aggravates the natural process of soil loss, resulting in accelerated erosion. Steep slopes are especially susceptible to increased rainwater run-off and erosion when cleared.

Soil erosion is a comprehensive form of soil degradation, encompassing chemical, physical and biological degradation. Erosion depletes nutrient stocks, decreases effective rooting depth, and reduces plant-available water reserves, all of which reduce crop yields (Lal 1981; Lal et al. 1989). Hence soil loss is frequently used as a proxy for general fertility decline. Soil erosion also affects yields directly, through loss of crop stand when seed and seedlings are washed or blown away, or buried.

The impact of soil degradation also includes off-farm effects, such as sedimentation, siltation and pollution of surface and ground water resources and infrastructure. Sediment yield and silt deposits in waterways are a function of soil loss upstream, although only part of it may

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[1] Climate is also a determining factor of natural soil fertility. Although climate is not an inherent property of the land, there is growing evidence that land use practices may affect local or regional climatic stability (Schneider 1991).

be due to erosion on farm land. Pollution of water resources can be traced more directly to agriculture, as natural soil degradation rarely results in contamination of water resources.

Both on-farm and off-farm impacts of soil degradation are difficult to measure. Scientists have therefore developed predictive models, based on statistical analysis of data from a few careful measurements. Such models are used to predict physical changes in soil properties, or to estimate soil loss, sediment delivery and deposition, infiltration and leaching. However, most models require considerable input data on climate, topography, soil type, vegetation and land use, which may be difficult to obtain.

Empirical models used to describe the processes of soil degradation range from simple regression models, relating soil and nutrient loss, to complex multi-equation models for analyzing soil and water interactions in watersheds. Probably the most widely-used model for predicting erosion under rainfall is the USLE, or Universal Soil Loss Equation (Wischmeier and Smith 1978). Developed in the United States to assist soil conservation planning, the USLE appears deceptively simple. The form of the equation is:

$$A = R \cdot K \cdot SL \cdot C \cdot P$$

where A is the mean soil loss per unit area, R is an index of the erosivity of rainfall, K is an index of soil erodibility, S is a slope steepness factor and L is a slope length factor, C is a crop cover and management factor, and P is a factor to allow for any erosion control practices.

Although simple to use in its final form, the underlying sub-models required to generate the input variables for the USLE are quite complex. Moreover, while the USLE model has been tested and confirmed across North America, some researchers dispute its validity in other parts of the world, as the sub-models used to estimate input variables appear to be highly location-specific (Stocking 1987). The model is also not suited to soil loss prediction beyond the field level, i.e. for entire watersheds or geographical regions. Many alternative soil loss models have been developed to address the short-comings of the USLE (eg. Williams 1975; Elwell 1978; Elwell and Stocking 1982).

## 2.2 Soil Degradation and Agricultural Productivity

The degradation of natural soil fertility, whether from cultivation or from natural phenomena, affects crop yields and farm income by reducing the ability of land to produce plant biomass. Of course, soil fertility is just one of many inputs to agricultural production; its relative importance varies with the farming system in place. Where fertile virgin land is easily accessible, farmers faced with declining yields may simply clear new fields. Where land is scarce, on the other hand, farmers have developed conservation measures to protect soil fertility or to reverse degradation. Protective measures range from so-called cultural methods, such as mulching and contour plowing, to mechanical means such as massive terraces and drainage systems. Soil fertility may be renewed or enhanced under cultivation, by application of organic and inorganic fertilizers, crop rotation (fallow), planting of "green manures" or other improvements. Such efforts can offset the destructive effects of natural or "man-made" soil degradation and prolong the productive life of the soil.

Empirical research on the impact of soil degradation on crop yields has concentrated on the effects of soil erosion. Most of this work is based on data from farms in North America. Leading predictive models based on this research include the Soil Productivity Index (Pierce, Larson, Dowdy and Graham 1983; Kiniry, Scrivner and Keener 1983), and the Erosion Productivity Impact Calculator (Williams, Dyke and Jones 1982). These models use statistical data to link changes in soil physical characteristics to the mean yeilds of standard crop varieties. Like the soil loss prediction models which underlie them, most erosion-yield models are voracious consumers of data. They are inappropriate for use where empirical statistics or the resources to collect them are scarce, i.e. throughout much of the tropics.

Empirical research on the erosion-yield relation under tropical conditions is extremely scarce. Some data suggest that the impact of soil erosion on crops may be more dramatic in the tropics than under temperate conditions, due to the relative fragility of tropical soils, or more extreme climatic conditions (Lal 1981, 1987; Stocking 1984).

## 2.3 Soil Conservation and Technological Change

Technical progress in agriculture has been rapid during the last century, particularly for temperate lands and crops. Significant advances have been made in crop breeding, mechanization and the use of chemical fertilizers. The technology of soil conservation has developed alongside other improvements. In addition to traditional conservation measures, farmers can now make use of plastic mulching, drip irrigation, 'no-till' cultivation or even laser-guided levelling machinery. Certain technical advances are achieved and undertaken in direct response to soil degradation; these may be described as *induced* technological change (Walker and Young 1986). Other *exogenous* refinements of farming practice may arise independently of concerns about soil fertility, but they can directly affect farmers' perceptions of or decisions regarding soil degradation.

The impact of soil degradation on productivity may be partly or entirely masked by exogenous technological change. Adoption of new hybrid crop breeds, for example, may boost yields so much that declining soil fertility is not perceived. Nevertheless, soil degradation clearly affects the long term productivity and profitability of farming. The benefits of improved technology are generally greatest on non-degraded land, while yields and profits would often be much higher if not for the effects of soil degradation (Young, Taylor and Papendick 1985). Moreover, the scope for additional exogenous technical improvements in agriculture remains uncertain, as many important tropical crops stubbornly resist the efforts of scientific research (Pinstrup-Andersen and Hazell 1987).

In many tropical countries technical progress in agriculture has been limited, especially for food crops. Meanwhile demand for arable land has increased with populations, leading farmers to reduce or abandon the traditional practice of letting degraded land recover through long fallow periods. The loss of soil fertility under continuous cultivation has been associated with stagnant or even declining yields, reflected in persistently low farm incomes. In some areas yields have fallen so far as to discourage further cultivation; arable land has been reduced to virtual desert and whole areas have become permanently uncultivable (Blaikie and Brookfield 1987).

## 2.4 The Soil as an Economic Asset

Evidence of the exhaustion of arable land under agriculture is found throughout history and in all parts of the world (Brown 1981; Stocking 1984). Some soil degradation may be related to long-term climatic trends, but most can be attributed to the effects of farming. A host of explanations have been offered for such commonplace destruction, from population growth and the advance of capitalism to policy failure, poverty and sheer ignorance on the part of farmers. These and other factors are discussed in more detail in Section 2.5.

Whatever the underlying socio-economic cause of soil degradation, from an economic perspective the effect is the same, namely that farmers behave as if they value the short term profits obtained from activities which degrade the soil more highly than they value the benefits of soil conservation. Such behaviour is not necessarily irrational. In fact, a comparison of the costs and benefits of conservation almost always justifies some amount of soil degradation, simply because the value of fertile soil is not infinite relative to other human needs. On the other hand, arable land is neither limitless nor costless to obtain, hence some form of conservation is often warranted. As with any economic asset, determination of an *optimal rate of exploitation* depends ultimately on a comparison of the benefits of conservation to potential returns from other investments and activities (Hotelling 1931; Clark 1976; Smith 1977). Farmers may be justified in liquidating the capital value of soil fertility, if the profits derived from non-sustainable agriculture will yield a higher economic rate of return in some other enterprise than in soil conservation.[2]

Farmer decision-making about soil degradation and conservation is explored in an extensive literature. Agricultural economists have developed a range of models to analyze incentives for and against soil conservation, usually in terms of changes in net farm income over time. The leading models are based on observations of farming practices in North America (see especially McConnell 1983; Shortle and Miranowski 1987; Walker 1982). Published empirical illustrations are also based largely on data collected from erosion-prone areas of the American Northwest and Canada (eg. Burt 1981; Dickson and Fox 1989; Miranowski 1984; Taylor and Young 1985; Walker and Young 1986). Attempts to develop models which account for the particular farming practices and impacts of land degradation in tropical countries include work by Abel 1990; Barbier 1990; Biot 1991; Bishop and Allen 1989; Cruz, Francisco and Conway 1988; Dixon, James and Sherman 1989 and 1990; Lutz, Pagiola and Reiche 1994; Magrath and Arens 1989; Stocking 1986; Southgate 1986; van der Pol 1992; Veloz, Southgate, Hitzhusen and Macgregor 1985. The most rigorous models permit analysis of the relative importance of different variables over time, including:

- input and output prices (including the opportunity cost of land, labour and capital);
- risk, uncertainty and information about conservation technology;
- the impact of cultivation techniques and crops on soil fertility;
- the impact of soil degradation on future crop yields;

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[2] Liquidation of the capital value of the land for direct consumption, if not compensated by some equivalent investment, would not be consistent with a *strict* economic definition of sustainable development, which requires that each generation pass on an equal or better resource endowment to its heirs than it received (Pearce, Barbier and Markandya 1990).

- the relation between mean yields, farmers' choice of crop and inputs, net farm income and land prices;
- the impact of on-farm soil erosion and resulting pollution or sedimentation on downstream water users;
- the time horizon over which potential crop losses are considered;
- the rate at which future losses are discounted relative to the present.

Virtually all economic decision models suggest that some depletion of soil fertility can be justified on economic grounds. The efficient or 'optimal' rate of depletion is defined as the point where the costs and benefits of soil conservation are exactly balanced (in marginal, present value terms). While the costs of soil conservation are easily determined, the benefits are often ambiguous and depend on a number of factors. In general, the benefits of soil conservation may be expressed in terms of the value of increased future crop yields, relative to yields on degraded soils (the on-site impact), plus the value of any off-site costs avoided (eg. sedimentation, siltation and pollution).

## 2.5 Diagnosis of Inefficient Land Use

One of the most widely invoked explanations of land degradation in developing countries is a high rate of population growth, leading to so-called "demographic pressure" on land resources and the spectre of more and more people competing for a fixed level of output. This Malthusian nightmare has been thoroughly discredited both in theory and practice and would not be worth rehearsing here except for its tenacious hold on the public imagination. Suffice it to say that studies from around the world have failed to establish a direct causal link between population growth and the degradation of soil and other renewable natural resources (for a recent review see Clay, Guizlo and Wallace 1994).[3]

More penetrating analysis has, however, identified a number of reasons why farmers may not choose an economically optimal rate of soil degradation. The widespread prevalence of market, policy and institutional failures means that farmers do not always take into account the full costs to society of soil degradation.[4] Such failures distort economic incentives, leading farmers to deplete soil assets at an economically inefficient rate, which may be too fast or too slow compared to the hypothetical ideal or *socially optimal* course of soil exploitation. Different authors use slightly different terminology but broadly speaking the underlying causes of inefficient land use may be grouped into the following categories:

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[3] Clay et al. (1994) accept that demographic pressure may have an indirect effect on land use and can delay the adoption of soil conservation measures, through its impact on farm size and the fragmentation of holdings. The empirical evidence, however, is scanty and inconclusive. In fact, some studies find a positive correlation between increasing population density and resource conservation (Mortimore 1992; English, Tiffen and Mortimore 1994). These authors suggest that increasing regional economic integration and opportunities for income diversification which have accompanied population growth are more important determinants of investment in resource conservation and improved productivity.

[4] For a general discussion of market and policy failure and natural resources see Bishop, Aylward and Barbier (1991); Pearce, Barbier and Markandya (1990); Repetto (1988).

- the presence of non-marketed and uncompensated *external impacts*;
- high rates of *time preference* that diminish the present value of future yield losses;
- the availability of technical *substitutes* for natural soil fertility and alternative assets;
- inappropriate *policy incentives* which inadvertantly discourage soil conservation;
- other technical and economic *constraints* which prevent farmers from adopting soil-conserving practices.

These factors are discussed in more detail below.

### 2.5.1 External impacts

External impacts or *externalities* are any costs or benefits which are not reflected in market prices. A typical negative externality resulting from soil erosion on agricultural land is the sedimentation of downstream reservoirs, hydroelectric facilities or irrigation channels. The protection of watersheds provided by tree plantations, orchards and other perennial crops is an example of a positive externality. Such off-site costs and benefits are not reflected in the prices of agricultural outputs, nor in farmer decision-making, but they are an integral part of the economic contribution made by agriculture. Because externalities escape the arena of existing markets, however, their effects are rarely documented. In addition, such environmental externalities are often difficult to measure.

### 2.5.2 Time preference

Time preference refers to the simple fact that most people prefer current income to future income. Pure time preference can be distinguished from the marginal opportunity cost of capital, which represents the scarcity value of savings and returns to alternative investments. Both pure time preference and the marginal opportunity cost of capital are reflected in the *discount rate*, which is commonly used to compare present and future costs and benefits.

Private individuals are often presumed to have a high degree of time preference, and thus employ higher discount rates, on average, than society as a whole. The rationale is that society can more effectively minimize risk by diversifying its investments; and of course society 'lives' forever while individuals do not. This divergence between public and private rates of time preference leads individuals to discount future benefits excessively and thus to consume assets that society as a whole would have them conserve (Markandya and Pearce 1988). In other words, society will ascribe a higher value to future crop yields foregone due to soil exhaustion than will farmers. Society is also likely to be more concerned about long run stability, sustainability and equity in agriculture, all of which may depend in some measure on conservation efforts (Conway 1988). Hence a socially optimal level of soil depletion will usually be significantly below the level tolerated by farmers.

Clearly all farmers do not display the same time preference. Private discount rates and patterns of resource use will vary with the level of household income, food security and access to opportunities for investment. High rates of private time preference may be associated with extreme poverty, when immediate subsistence is uncertain. Land tenure problems can also engender high rates of time preference, wherever insecure land use rights or shared access to scarce resources discourage investment and prudent exploitation (Magrath 1989a; Southgate 1988). Private time preference is notoriously hard to measure. Some studies employ the market rate of interest, ie.the opportunity cost of capital, as a rough proxy, but the two are not equivalent.

Most industrialized countries are endowed with well developed markets, clearly defined and secure private ownership of agricultural land, large non-agricultural sectors and relatively high farm incomes; hence we might expect only slight divergence between social and private discount rates. In many developing countries, however, the combination of widespread poverty and poorly developed land tenure institutions and rural capital markets may imply high rates of private time preference, hence significant divergence between public and private discount rates (Barbier and Burgess 1992a).

### 2.5.3 Substitutes

Technical innovation is largely devoted to devising substitutes for, or increasing the productivity of scarce factors. The depletion of a scarce natural resource poses a threat when it is considered *essential* to future economic opportunities, ie. if there is no apparent substitute for the resource, if degradation is for all practical purposes irreversible and/or if its future value is uncertain but believed to be high (Pearce, Barbier and Markandya 1990). Fertile land may be considered an essential resource, particularly in many developing countries, where subsistence agriculture accounts for a substantial proportion of national income and an overwhelming segment of the labour force. The prominent role of agriculture in national welfare in such countries justifies concern about the possible lack of substitutes for natural soil fertility, and the scarcity of alternative economic opportunities.

Natural soil fertility may seem less essential in the industrialized nations, where fertilizer, irrigation and other technical inputs offer farmers considerable flexibility, and where alternative economic opportunities are more widely available. Similarly, from a private perspective, there are almost always substitutes for arable land, since individual farmers can often find alternative or supplementary occupations, and few people consider the value of their land in terms of national economic security. Hence farmers tend to treat soil fertility as just one income-producing asset among many.

### 2.5.4 Policy incentives

Most countries have instituted a host of policies affecting agriculture, including measures which stimulate production, others which dampen output, and a number with influence the way crops are grown. Many of these schemes have significant impacts on land use and soil conservation practices, because of the way they modify relative returns to certain crops, inputs or methods of cultivation. Policies may aggravate the problem of excessive soil degradation, or alleviate it.

Changes in land use patterns can arise directly and intentionally, through policies affecting the price of farm land or incentives for conservation (eg. land taxes or subsidies). In many cases, however, the effect of agricultural policy on soil conservation efforts is entirely incidental. For example, limited evidence suggests that subsidies for non-labour inputs, notably inorganic fertilizers, can artificially reduce the private costs of soil degradation, as they cheapen the perceived cost of substitutes for natural fertility (Barbier 1990).[5] Similarly, price supports and export subsidies for certain crops can lead to cultivation of marginal or vulnerable lands, which might otherwise be left to pasture or woodland.

In addition to agricultural policy, other economic policies can also have profound effects on land use. Virtually any policy which distorts the market prices of agricultural inputs and outputs can alter incentives for soil conservation. The impact of specific policies on farmer decision-making and land degradation is often ambiguous, however, making generalization difficult. In addition, impacts on households will vary to the extent that policies affect certain groups more than others. The links between economic policy and land use are explored in more detail in Barbier and Bishop (1992), Barbier and Burgess (1992b), Barret (1989) and Southgate (1988).

### 2.5.5 Other factors

Soil conservation requires access to labour, capital (including land, equipment and materials, or the funds to obtain them) and information (technology). Poorer farmers often lack access to one or more of these inputs, preventing them from adopting conservation measures. They may fail to perceived the gravity of soil degradation or lack information about available soil conservation measures. Even when they know of appropriate technologies, farmers may lack access to sufficient labour to undertake soil conservation measures on their own, and may also suffer limited access to capital with which to hire additional manpower or purchase any tools required.

For example, in many areas the best time to install or maintain soil conservation structures is at the beginning of the growing season, when soils are softened by rain and vegetation cover is light. But this is also the moment of peak labour demand for field preparation and planting. The true opportunity cost of soil conservation is thus often higher than at first appears, when considered in relation to other demands on farmers' resources.

## 2.6 Conclusion

This chapter reviewed basic concepts in the economics of soil fertility and degradation, including a description of:

- the physical processes of soil formation and erosion,
- methods of measuring and predicting soil degradatation,
- the impact of degradation on agriculture and farmers' responses, and
- the role of technical progress in counter-acting soil degradation.

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[5] On the other hand, lack of access to modern inputs can perpetuate farming practices that needlessly damage the soil. Moreover, input subsidies may raise farm incomes, enabling poor farmers to engage in more far-sighted behaviour and thus encouraging increased investment in land assets (Barbier and Burgess 1992b).

The main focus of the chapter was on the economics of optimal soil management and, in particular, why farmers do not always choose a level of soil conservation that is most efficient, from society's point of view. A range of factors were invoked to explain this discrepancy, including:

- external costs and benefits;
- high rates of time preference,
- the availability of substitutes,
- public distortions, and
- lack of access to labour, capital and information.

In the following chapter, we discuss a range of different economic techniques which may be used to elicit the cost of soil degradation or the benefits of soil conservation in monetary terms, with illustrations drawn from the literature.

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# 3 VALUING THE COSTS OF SOIL DEGRADATION

The negative consequences of soil degradation under agriculture are widely recognized, but until recently few attempts had been made to estimate the magnitude of the costs involved. Economic losses arising from soil degradation may be divided into *on-site* and *off-site* costs. On-site costs refer to the direct effects of soil degradation on the quality of the land resource itself, often expressed in terms of reduced agricultural productivity.[6] Off-site costs refer to the indirect effects of soil degradation, and usually take the form of *externalities*, as described above. Most off-site costs can be traced to the effects of silt, soil nutrients or agro-chemical products washed into surface water or leached into subterranean aquifers by rainfall and irrigation run-off.

A range of analytical techniques are used to evaluate the impacts of soil degradation in terms of economic costs and benefits. Published empirical studies are confined largely to analysis at the level of individual farms or watersheds. On-site impacts are most frequently studied, generally by analysis of the effect of soil loss on crop production. Assessment of off-site effects has been hampered by a lack of physical data.

Attempts to estimate the costs and benefits of soil conservation on a regional or national level encounter serious methodological problems. Significant errors can arise when data and techniques obtained at the level of individual field plots are extrapolated on a broader scale (Stocking 1987). One major complication arises from the fact that eroded top soil does not simply disappear. Most eroded sediment is deposited in low-lying areas, to the potential benefit of floodplain agriculture. This effect may be significant, as in the Nile River Valley, where farmers traditionally depended on silt deposited by the river to fertilize their land. Any assessment of the cost of soil erosion upstream must be balanced by an account of potential benefits to downstream land users. Other problems can arise from the aggregate nature of agricultural statistics. In addition to the masking effects of increased fertilizer use or technological progress, or expansion of agriculture onto virgin land, aggregate yield and land use data can hide important shifts in cropping patterns, as farmers adapt to soil degradation. Efforts to evaluate the wider economic impact of soil degradation must be carried out with extreme care.

## 3.1 Land Values (Hedonic Pricing)

Ostensibly the most direct approach to valuing soil degradation, hedonic pricing compares the sale or rental price of plots which differ only in the extent of physical degradation. In principle, the difference in productive capacity will be reflected in prices, which in turn reflect the present value of net returns over time.

Hedonic pricing has been used to value the effects of soil degradation on agricultural land prices in North America, with mixed results. Hertzler, Ibañez-Meier and Jolly (1985)

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[6] Some on-site impacts of soil degradation may be indirect, for example when shifting cultivation exhausts the natural fertility of plots of land, leaving them less productive of valuable secondary wild plant and animal species.

evaluated the loss of future productivity due to soil erosion on farm land in Iowa at over $400 per hectare, but found that this cost was not reflected in land prices. Gardner and Barrows (1985) demonstrate that conservation is only capitalized into land prices when the need for such investment is obvious, using data from S.W. Wisconsin. These studies suggest that soil degradation is not automatically reflected in land prices, even where markets are relatively well developed, due to lack of information on the extent of erosion and its effect on productivity, and to the masking effect of exogenous technical improvements.

Hedonic pricing is generally *not* applicable where land markets are poorly developed, due to tenure insecurity, or when land markets are distorted by speculation or public policy. These constraints are often particularly acute in some developing countries. Even when such complications do not arise, hedonic pricing may understate the full cost of soil degradation to society, as it captures only costs and benefits perceived by the parties to market transactions, i.e. the reduced productive capacity of the land. Off-site costs are ignored, as are losses arising from any divergence between private and social time preference.

### 3.2 Productivity Effects

Soil degradation affects agricultural productivity directly - for example when erosion washes away or buries crops - or indirectly, due to changes in soil properties. An intuitively appealing method of valuing these on-site costs is to estimate farm revenues foregone due to soil loss or reduced top soil depth. This approach relies on empirical estimates of the impact of erosion on crop or livestock yields, combined with farm budget data. Off-site costs are ignored.

In an early study of the costs of soil erosion in Java (Magrath and Arens 1989), the discounted present value of current and future *net* farm income foregone due to annual soil loss was evaluated at $68 per hectare, based on rough estimates of yield decline over time. In aggregate terms this was equivalent to about 3% of agricultural GDP.

Other studies suggest far more modest losses. A recent case study of Zimbabwe links estimated soil erosion to crop yields using two empirical models of the erosion-yield relation (Grohs 1992). First, average annual sheet erosion on cropland is estimated for every district using the Soil Loss Estimation Model for Southern Africa (SLEMSA), originally developed by Elwell and Stocking (1982). Yield impacts are then calculated using the CERES and EPIC models. The former links erosion, expressed as a reduction in the depth of the fertile horizon, to soil water holding capacity and thus to maize yield. Yield losses for maize per centimeter of soil loss are estmated at 0.3 - 1.4%. EPIC links erosion to changes in both soil chemical and physical properties (i.e. nutrient losses as well as depth) and accordingly generates slightly higher estimates of yield loss (0.7 - 3.3% per cm soil loss for maize). Calculated yield losses are combined with farm enterprise budgets and data on average yield and cultivated area to derive estimates of the on-site cost of erosion, reported as US$ 0.7 - 2.1 million in 1988/89. Finally, priority areas for conservation investment are identified on the basis of predicted erosion, current agricultural production and agricultural potential.

A major difficulty with this approach is that the link between soil degradation and yields of crops or livestock is often not well defined. A common error is to compare yields on eroded soil to yields on 'virgin' land. The gap is supposed to reflect the cost of soil loss. However, this approach implicitly assumes that crops could be grown without having any effect on soil fertility, which is almost never the case. More realistic methods account for the higher costs or lower average yields associated with conservation farming, by comparing long run net farm income with and without conservation measures (Fox and Dickson 1988).

An alternative method which sidesteps the difficult link between erosion and yields is to estimate the productive life span of the soil, based on estimates of the depth of the fertile horizon, the rate of soil formation and mean annual soil loss, and the minimum soil depth needed to support agriculture (Elwell and Stocking 1984). This approach is shown to good effect in studies of soil degradation under communal livestock grazing in central Botswana, using the EPROM erosion-productivity model (Biot 1988, 1991). Results indicate a mean soil life of 420 years under prevailing stocking densities. No significant difference was found between ground cover and estimated soil loss under current livestock densities and under the much lower, officially recommended densities, calling into question the long-standing efforts of government to promote destocking on communal lands as a means of reducing land degradation (Abel 1990).

### 3.3 Replacement Cost

Another means of measuring the on-site cost of soil degradation is to estimate the cost of additional inputs required to compensate for reduced soil fertility. This may include increased labour inputs, or increased application of fertilizer to compensate for the loss of plant nutrients due to erosion, leaching and volatization, or removed in crop residues.

One such study evaluated losses of three major plant nutrients based on measures of soil erosion on farmland in Zimbabwe (Stocking 1986). Losses were expressed in terms of the cost of applying equivalent quantities of nutrients in the form of chemical fertilizer. The study concluded that the total cost of replacing plant nutrients lost to soil erosion on agricultural land in 1986 would have been US$1.5 billion (3.5% of GDP), or about $50/ha/year on communal farm land.[7]

A more recent study developed detailed nutrient balances for the main cropping systems in southern Mali, including both annual additions to and subtractions from soil nutrient content (van der Pol 1992). Large deficits were found for nitrogen, potassium and magnesium under cultivation of traditional cereal crops, cotton and especially groundnuts. Nutrient losses are attributed mainly to crop uptake, erosion (average 8 tons/ha for all crops) and volatization-denitrification. Based on estimates of current soil nutrient reserves, the author predicts a catastrophic breakdown in productive capacity about 30 years hence, due to loss of soil structure and irreversible erosion. Nutrient losses are further expressed in terms of equivalent quantities of chemical fertilizer and valued using prevailing market price. Mean estimated losses are US$59 per hectare, or about 40% of average gross margins. By comparison,

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[7] Note that losses estimated by this method are significantly greater than those obtained using the productivity approach (Grohs 1992). Such contrasting findings underscore the need for caution in using a replacement cost approach.

current rates of fertilizer use are equivalent to about $18 per ha. Nevertheless, the author acknowledges that increased fertilizer applications are not justified given current prices and potential yield benefits.[8]

While the replacement cost approach is intuitively appealing and relatively simple to apply, it can be misleading. Normally, we would expect a farmer faced with declining yields to select the least expensive available option to maintain productivity. The same principle applies when using a replacement cost approach to value the loss of natural soil fertility. Thus it is not appropriate, for example, to value nutrient losses in terms of the cost of chemical fertilizer if, in fact, it is more profitable for a farmer to clear a new field (assuming land is abundant and labour is cheap).

Even where such problems do not arise, the replacement cost approach may exaggerate or under-state the impact of soil erosion. For example, nutrient losses do not reflect the effects of erosion on soil structure or depth, which are also important determinants of fertility (Stocking 1984). Use of a nutrient replacement approach would not capture this effect. On the other hand, on-site costs may be overstated if no allowance is made for the natural process by which plant nutrients become available for crop growth (eg. the rate of mineralization of nitrogen). It is not always clear just what portion of total eroded nutrients would have been taken up by crops and thus boosted yields.[9] Finally, as with the productivity approach and hedonic valuation method, off-site costs are ignored.

## 3.4 Net Benefits of Conservation

Finally, the on-site cost of soil degradation may be approached from another direction altogether, drawing on empirical measures of the net benefits derived from soil conservation. These are usually expressed in terms of yield differentials, relative to yields on similar 'control' plots without conservation.

The benefits of soil conservation are normally expressed net of cost. Since most conservation measures involve an up-front investment, while benefits are spread over subsequent years, the calculation of net benefits implies a comparison of current expenditure with future income. Conventional analysis requires that future income be discounted, hence the benefits of

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[8] A subsequent focused study of a single cropping system -- the cotton-cereal-cereal rotation promoted throughout the region -- uses van der Pol's data on soil nutrient balances but adds the impact of grazing and manuring by draught animals (Girdis 1993). Using different price data and more modest assumptions about the efficiency of nitrogen replacement by chemical fertilization, the author estimates average losses of US$78 per hectare (of which $16 per ha for draught cattle), compared to gross revenues of about $253 per ha generated by this system. The author further assesses the sensitivity of these results to potential policy reforms, i.e. a devaluation and the removal of EC subsidies which depress the price of domestic beef.

[9] A further complication is that eroded sediments contain higher concentrations of plant nutrients than the soils from which they come (the difference is expressed in terms of the 'enrichment ratio'). Hence data are required on the nutrient content of eroded sediments as well as gross soil loss.

conservation will be discounted relative to its cost. Depending on the rate of discount, the present value of net benefits may be positive or negative.

A recent review of cost-benefit analyses of soil and water conservation programs in Central America found that rates of return were negative where soils were very deep, i.e. where the impact of erosion on crop yield is negligible (Lutz, Pagiola and Reiche 1994). The authors noted a high correlation between apparent profitability and rates of adoption, suggesting that farmers are aware of the relative costs and benefits of alternative cultivation practices and conservation measures. Another study of the use of Vetiver grass and contour bunds in soil conservation compared yield benefits to farmer costs, per hectare treated (Magrath 1989b). Estimated rates of return in net present value terms for the two technologies varied from 22% to 95%, depending on the assumed level of yield increase and the proportion of soil loss prevented. Sensitivity analysis examined the effect of changes in the length of the planning horizon, the discount rate used and the share of benefits captured by the farmer.

A particularly ambitious case study of Ghana and Nigeria combined an assessment of the potential benefits of soil conserving technologies with estimates of the negative impact of soil degradation and shortened fallow periods on crop yields (Knowler 1993). Erosion estimates were generated with the USLE. Potential yield benefits are derived from the literature, while the impact of soil degradation is obtained from various sources, including existing models of the link between erosion and crop yield (Lal 1987), previous estimates of the minimum fallow period required to maintain soil productivity, for different soil types, and early measurements of yield decline under continuous cropping (Nye and Greenland 1960). These data are used to conduct cost benefit analyses of 18 different technologies. Potential benefits include reduced annual decline in yields, relative to the base case, as well as any immediate yield increment. Costs include the loss of land area available to crops and incremental labour. Results include the estimated financial and economic rates of return (IRR and ERR) for each technology, as well as returns to labour and the subsidy that would be required in order to achieve a benefit-cost ratio of 2:1, in present value terms. Estimated economic returns account for various factors which farmers might not consider on their own, such as the impact on national food security (evaluated in terms of the border price of imported food), sedimentation of reservoirs, loss of non-timber forest products, shadow wages, exchange rate distortions and programme management costs. Assuming a relatively high discount rate of 20%, for the financial analysis, only a handful of technologies were found to exhibit superior returns and then only under certain conditions (2 technologies in Nigeria and 6 in Ghana).

Note that the net benefits of conservation measures, in terms of retaining the soil *in situ*, may be difficult to distinguish from other effects, notably water retention and silt capture. Most measures reduce the impact and/or run-off velocity of rainfall and thus increase infiltration and soil moisture. In arid or drought-prone areas the effect on yields can easily exceed that of soil retention. In more humid areas, on the other hand, the same water-harvesting effect may result in water-logged soils and *reduced* yields. Another result of soil conservation measures is to capture and accumulate silt suspended in run-off from areas upstream of the conserved field. The additional increase in yields from such *soil harvesting* is distinct from the benefit of retaining top soil that was already on the field and, in some cases, may be the main aim of farmers' conservation efforts.

### 3.5 Off-Site Costs: Pollution and Sedimentation

Estimating the *off-site* costs of soil degradation involves a slightly different approach than that described above. In general, off-site costs arise from the negative impact of agricultural run-off on downstream water users. Increased costs may be associated with changes in the quantity or the quality of run-off.

Whereas natural vegetation effectively soaks up rainfall for its own use, releasing much of it into the atmosphere through evapo-transpiration, tilled fields and grazed pasture capture less water overall and release it rapidly in the form of overland flow, resulting in brief but intense run-off events. In areas of high rainfall and steep relief, a change in run-off volume and variability under cultivation can result in increased risk of flood damage or reduced reliability of flows to downstream users.

High levels of soil loss under agriculture can lead to increased sediment load and heavy deposits of silt downstream. Agricultural land is typically a minor source of sediment yield, relative to the effects of mass soil movement and stream bank disturbance arising from road building or other major construction projects. Nevertheless, the impact of farming on total sediment yield is significant in many watersheds (Southgate 1986). While increased sedimentation may benefit floodplain agriculture, it will increase costs associated with dredging and clearing irrigation and shipping channels, ports and harbours. Siltation will also reduce the life span and storage capacity of reservoirs, resulting in diminished benefits from hydro-electric power generation and gravity-fed irrigation systems. Furthermore, siltation increases the turbidity of public water supply, requiring increased filtering and reducing equipment life in water treatment plants.

Analysis of soil erosion on Java (Magrath and Arens 1989) estimated annual off-site costs at US$ 25.6 - 91.2 million, as compared to $315 million for on-site costs (productivity losses). Off-site cost estimates were as follows: increased operation and maintenance costs to remove accumulated silt in irrigation systems (US$7.9-12.9 million); total dredging costs to remove silt in major ports and harbours (US$1.4-3.4 million); reduced hydroelectric output and irrigated crop production resulting from sedimentation of reservoir capacity (US$16.3-74.9 million). A similar analysis of two watersheds in the Philippines (Cruz, Francisco and Conway 1988) estimated annual off-site costs at about US$9.4 million. 99% of this amount reflects the opportunity cost of reservoir capacity devoted to the accumulation of sediment ('dead' storage), expressed in terms of net irrigation benefits foregone.

Agricultural run-off may also contain residues from fertilizer and pesticide products, or from farm wastes. These may be leached into subterranean aquifers or washed into surface water, polluting potable water supplies. They can also impinge on natural fisheries and hatcheries, with direct effects on returns to fishing, as well as indirect effects on animal and human health. However, little empirical information is available to quantify these impacts, let alone to estimate their cost in economic terms (Conway and Pretty 1991).

### 3.6 Valuation for Policy Analysis

In practice, land husbandry policy should be based on an assessment of the marginal economic costs and benefits of soil conservation (including adjustment for policy distortions). Analysts should also attempt to anticipate potential price changes or shifting patterns of land use which may be associated with widespread adoption of soil conserving technologies. Marginal analysis implies that conservation measures and/or subsidies should be applied to the point where the cost of conserving another unit of soil (i.e. avoiding another unit of soil loss) just equals the benefit of doing so, from the perspective of society as a whole. An adequate accounting for potential price and production shifts requires an explicit treatment of the linkages between total output, prices, wages and patterns of land use, any or all of which may vary if land husbandry policy results in significant change in cultivation practices across a region or nation.

Where sufficient data are available, it may be possible to estimate the aggregate loss of economic welfare arising from excessive soil degradation, and thus the potential gain from increased conservation efforts. This implies estimation of marginal cost and benefit curves for soil conservation. Estimating the former is relatively straightforward. Even where data on the direct costs of conservation technologies are not available for a given area, it is often possible to adapt data from other locations, provided that allowance is made for real differences in labour inputs and costs. Some adjustment of marginal cost figures may also be required to account for subsidies for conservation efforts, in the form of agricultural extension services or direct payments for land taken out of production.

On the other side of equation, the benefits of soil conservation can be expressed in terms of on-site and off-site costs avoided. In general, marginal benefits will decline with the proportion of soil loss avoided, in accordance with the law of diminishing marginal returns. However, marginal benefits may vary widely from one country to another, due to differences in crops and yields, use of agro-chemical inputs, returns to agriculture and the level of development of hydroelectric, irrigation and river transport infrastructure.

By distinguishing on-site from off-site costs and private from social discount rates it may be possible to define two marginal benefit curves: one private and one for society as a whole. This difference is depicted in Figure 1, where $Q_p$ indicates the amount of soil conservation chosen by private producers and $Q_s$ shows the quantity preferred by society.[10] The shaded area between the private and social marginal benefit curves, up to the point $Q_s$, represents economic welfare foregone if private interests prevail.

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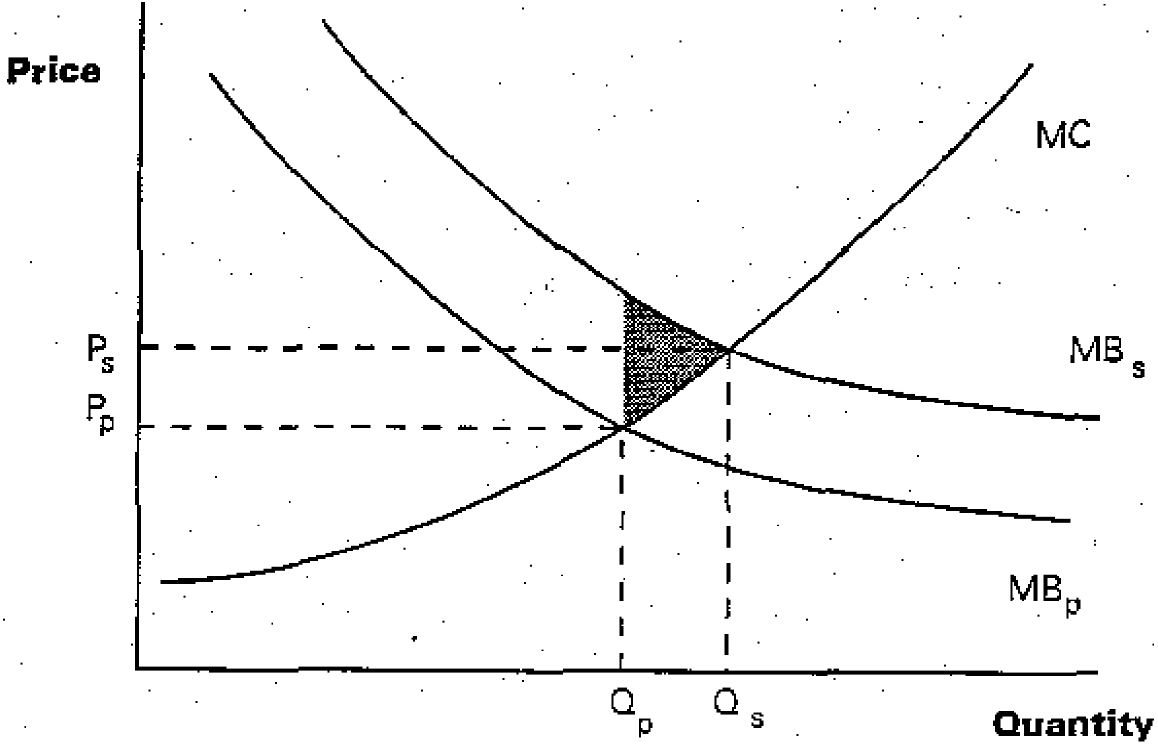
[10] Q may also refer to top soil depth, reduction in run-off or some other measure of conservation effectiveness. P refers to price. The marginal benefit and cost curves shown in Figure 1 are hypothetical but conventional, implying that benefits decrease and costs increase with the extent of conservation. It is assumed that the marginal cost of conservation is equivalent for society and for private producers.

Figure 1: Marginal Costs and Benefits of Soil Conservation



With respect to the analysis of potential price changes and other general equilibrium effects, additional information is required on the relevant linkages at a sectoral or national level. A good example of this type of analysis is provided in a study of the linkages between economic policy, land use and labour markets in Asia (Coxhead and Jayasuriya 1992). The authors develop a simple general equilibrium model of an economy with two regions (upland and lowland) linked by national markets for labour and food. The upland area comprises two sectors (exportable tree crops and non-traded food crops) and two factors of production (land and labour). The lowland area comprises two sectors (exportable manufacturing and non-traded food crops) and three factors (capital, land and labour). Labour is assumed to be mobile across sectors and, in certain simulations, across regions. Land in the uplands is mobile across the two different types of crop. Upland food crops are assumed to be relatively labour-demanding and erosive. There is a single national market for food, with prices determined endogenously and explicit treatment of income effects.

The authors use the model to explore the direct and indirect implications of various exogenous shocks, including technical progress in lowland food crops, upland food crops and upland tree crops as well as foreign investment in manufacturing. The appeal of the model is the way that food and labour markets transmit the effects of shocks in one sector or region to another, and vice versa. For instance, the authors argue that technical progress in lowland food crops (the "Green Revolution") will lead farmers in upland areas to produce less food and more tree crops. This will tend to reduce erosion, although upland wages will decline if labour markets are segregated. In contrast, a manufacturing boom will raise lowland wages, drawing labour out of lowland agriculture and encouraging food production in upland areas and thus resulting in increased erosion. The authors conclude that investment is required in both upland tree crops and lowland food crops in order to avoid unintended adverse impacts on upland incomes or the environment.

## 3.7 Conclusion

This chapter reviewed a range of valuation methods used to assess the on-site economic costs of soil degradation, including:

- the impact of soil degradation on land values (hedonic pricing),
- the impact on crop yields and net farm income (productivity effects),
- the costs of compensating for soil degradation (replacement cost), and
- estimating the net benefits of soil conservation.

The off-site impacts of soil degradation were also considered, with various ways to account for them in economic terms. Finally, the use of valuation for policy analysis was briefly reviewed, including the need to consider marginal costs and benefits, price effects and intersectoral linkages.

The following two chapters present illustrations of the change-in-productivity approach to valuing the on-site costs of soil degradation. These are drawn from economic studies of soil erosion on agricultural land in two African countries: Mali and Malawi. The study of Mali has been previously published by the World Bank (Bishop and Allen 1989). The study of Malawi is based on a consultant report but has not been published before (Bishop 1990). The paper concludes with a brief summary and discussion of the main methodological issues and priorities for further research.

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# 4 THE ON-SITE COST OF SOIL EROSION IN MALI

## 4.1 Background and Introduction

Mali is one of the poorest countries in West Africa and the world, with a per capita income of about $280 in 1990. In that year, agriculture accounted for almost half of Mali's gross domestic product (GDP) and the bulk of export revenues. Over 80% of the labour force is directly involved in farming. Virtually all agricultural production in Mali is labour intensive, and carried out by households operating at a subsistence level. Conservation efforts are rudimentary at best.

In recent years both drought and demographic pressure have put enormous strains on the natural environment of Mali. Tree and grass cover have dwindled, with disastrous consequences for the soil, which is left bare to the erosive winds and rains of the tropics. Crop and animal production has certainly suffered from declining soil productivity, although to what extent is unclear. For a nation still largely dependent on agricultural production, these phenomena appear to constitute a serious threat to future economic welfare.

Some efforts have been made to quantify the extent of physical decline locally (eg. Delwaulle 1973, Lal 1976, Roose 1986); far fewer to evaluate ecological deterioration on a national or regional scale. Little progress has been made in determining the economic impact of environmental degradation, nor in distinguishing efficient depletion of natural resources from excessive exploitation.

This chapter describes an attempt to answer the latter questions for one important renewable resource - the soil. Section 4.2 presents various reasons why Malian farmers are not managing soil resources efficiently, in economic terms. Section 4.3 defines the scope of the analysis and the approach used to assess the economic impact of soil degradation. Section 4.4 describes the construction of a Geographic Information System (GIS), based on an existing atlas of land resources. This database is used to estimate average rates of soil erosion, in physical terms, for different areas. Section 4.5 goes on to link estimated soil losses to crop yields and then, in Section 4.6, to changes in net farm income. The resulting estimates of economic losses are compared, in Section 4.7, to the costs of alternative soil conservation technologies, in order to identify priority areas for conservation investment. In Section 4.8, total losses are calculated for the nation as a whole, including estimates of the aggregate loss of economic welfare due to inefficient soil management. Finally, in Section 4.9, sensitivity analysis is conducted on key variables.

## 4.2 Market Failures in the Agricultural Sector

Empirical and anecdotal evidence suggests that land degradation in Mali is not occuring at an efficient rate, due to various market imperfections. High rates of time preference on the part of subsistence farmers, lack of secure rural land tenure and uncompensated off-site impacts combine to create a wedge between private and social costs.

As discussed in Chapter 2, the depletion of non-essential renewable resources can sometimes be justified on the basis of simple time preference. However, there is reason to believe that the rates of time preference implicit in the land-use decisions of Malian farmers are not socially optimal. Their rates of time preference are certainly far higher than the range of discount rates used in investment decisions by the Malian government, or by foreign aid agencies.

The difficulty is how to measure farmer time preference. The opportunity cost of capital is a rough but imperfect indicator. Studies of informal rural credit systems in West Africa suggest that rural producers' nominal cost of capital is between 50 and 150% annually (Shipton 1987).[11] Such high rates of interest imply that farmers will require a high rate of return on investment, although we cannot assume that rural producers' rate of time preference is equivalent.

Another reason for believing that farmers' rates of time preference are very high and that land degradation is excessive lies in the insecurity of rural land tenure in Mali (Gorse and Steeds 1987). As in most West African countries, rural lands are held in common, under indigenous systems of management. The Malian state generally recognizes only usufruct rights over land, except where it has formally granted free hold title (mostly confined to urban areas). Because the state has not formally recognized indigenous land management systems, and can transfer use rights at will, rural producers cannot be certain of long-term access to the land. It is thus argued that they will discount the future benefits of land husbandry at an excessive rate, leading them to deplete the land in order to maximize present income. Recent drought conditions and acute rural poverty are added incentives to impatient economic behavior.

Finally, Malian farmers cannot be expected to account for any off-site impacts of land degradation in their decision-making, as there are no mechanisms in place which would lead them to do so. Siltation and sedimentation due to soil erosion on farm land may affect the productivity of fresh-water fisheries, clog irrigation systems and increase the cost of keeping shipping lanes open. On the other hand, the deposition of nutrient-rich eroded sediments in low-lying areas may benefit floodplain agriculture. The net off-site impacts of soil erosion are unknown.

### 4.3 Scope of the Analysis and Valuation Method

The focus of the study is the depletion of soil resources under cultivation of annual field crops in Mali. This choice is a function of the relative importance of this type of farming in overall primary production, the vulnerability of the resource to depletion in this use, and the potential for conservation. Moreover, only the on-farm economic impacts of soil depletion are considered and only on currently cultivated land. Lack of relevant data prevent

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[11] Private money lenders may be obliged to charge such high rates due to the small scale of their operations and the extreme vulnerability of the rural economy to climactic fluctuations. Creditors are unable to spread loans across areas and activities wide ranging enough to compensate for the frequent local droughts typical of the Sahel.

an analysis of off-site costs, as well as the impact of soil depletion on fallow, forest and rangelands, although these may be significant.[12]

The study examines the effects of soil degradation on both traditional subsistence farming and export agriculture. The food crops considered are those covering the largest surface areas, i.e. millet, millet with cowpea, sorghum, and maize. Rice is excluded from the analysis, as virtually all of it is grown on seasonally flooded lands, which do not suffer significant net soil loss. The impact of soil degradation on cotton and groundnut production--two of Mali's most important export crops--is also evaluated.

The method of valuation used is the change-in-productivity approach.[13] More direct valuation methods were ruled out due to a lack of relevant information. In particular, hedonic pricing is not feasible because there is essentially no *legal* market in agricultural land in Mali and data from the illicit market are difficult to collect. The value of the soil is therefore determined indirectly, by linking soil degradation, crop productivity and farm income. The first step is to estimate current rates of soil degradation, in physical terms.

## 4.4 Estimating Soil Erosion

Based on previous research in Nigeria, carried out at the International Institute for Tropical Agriculture (IITA), physical soil loss in tons per hectare per year can be considered a proxy for declining soil fertility. Multiple regression analysis of data from controlled experiments at IITA revealed that soil loss measured in tons per hectare was a reliable predictor of changes in soil nutrient content, soil pH, and moisture retention (Lal 1981). Moreover, the latter variables accounted for almost all of the annual variation in yields of maize and cowpea.

The Universal Soil Loss Equation (USLE) is employed to estimate current rates of soil erosion in Mali. The main reason for using the USLE is that much of the climatic and soil data collected in West Africa during the past three decades were intended for its use. More specifically, the data available on land resources in Mali are readily converted into a form usable by the USLE model, while the data requirements of more sophisticated soil loss prediction models cannot be met with current information.

The Modified Universal Soil Loss Equation (Williams 1975), for example, is designed to estimate soil loss on a regional scale but requires estimates of runoff volume and peak flow

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[12] A potential topic for future research is the economics of rangeland degradation. Analysis of the productivity of Sahelian rangelands suggests that sustainability cannot be maintained at any useful level of production (Penning de Vries and Djiteye, 1982). While traditional, extensive production will prolong the life of pasture, virtually every level of use will eventually deplete the resource. This argument, if true, implies that Mali should consider its pastures a non-renewable resource. The question then becomes one of deciding how quickly to liquidate the asset.

[13] Annex A describes and compares the results obtained using a replacement cost approach, which involves estimating the cost of replacing essential soil nutrients with chemical fertilizer substitutes, based on a model developed for Zimbabwe (Stocking 1986).

rates, neither of which can be readily derived from available data. Data are also too thin to permit use of two soil loss estimation models which, although less widely tested, were developed for the same agro-climatic zone as Mali (southern Niger), by Heusch (1980) and Vuillaume (1982). The former requires measurements of suspended sediment load at regular intervals along a watershed. The few gauging stations situated along the Niger River would permit only very gross estimates of soil loss and would neglect a great deal of erosion and re-deposition in small upland catchments.

Vuillaume's models are even more demanding of data. The following parameters are all unavailable for Mali: the depth of surface runoff, precipitation during the first 20 minutes of each storm event and the time separating the start of each storm from its maximum intensity.

Another model considered for this study is the Soil Loss Estimation Model for Southern Africa (SLEMSA), developed by Elwell and Stocking (1982). SLEMSA requires only three input parameters: the rainfall energy interception of each crop, the mean soil loss on a bare fallow polot of known slope and a topographic factor for other slopes. The first parameter has been measured for crops in Zimbabwe and may be applicable to Mali. The topographic input required by SLEMSA might be inferred from existing data on Mali, as is done for use with the USLE (see Section 4.4.4). The difficulty lies with the second variable, which combines climatic erosivity and inherent soil erodibility. SLEMSA thus requires empirical data for rates of erosion on bare soil, over a representative range of environmental conditions. The few published measurements of soil erosion on bare fallow plots from countries neighboring Mali are not sufficient.

While the USLE is better adapted to the available data, it remains a compromise solution, for two reasons: (i) the USLE is designed for the study of small field plots, not for regional surveys, and (ii) its validity in the tropics, despite three decades of study, is still a matter of controversy. The former is a more critical issue, since the USLE ignores soil deposition. Considering that as little as 10% of the sediments eroded in any period reach a major river (Walling 1984, Crosson 1983), it is clear that soil deposition will have a significant mitigating effect, at least where such deposits occur. To allow for soil deposition in catchments, the model used here ignores all predicted soil loss on land areas known to receive significant alluvial deposits.[14] As for the applicability of the USLE in the tropics, Roose (1977) maintains that the equation is a reliable predictor of soil loss for the majority of cultivated lands in West Africa, especially for the gentle slopes and iron-rich soils typical of Mali.

The most important caveat on use of the USLE in this study, or for that matter any soil loss estimation model, stems from the lack of published measurements of soil erosion in Mali. It is thus impossible to verify estimates of soil loss except, very roughly, by reference to field

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[14] Soil loss and sediment deposits have been measured at different geographic scales in West Africa, from field plots of a few square meters to watersheds of many tens of square kilometers. These studies suggest that most eroded sediment is deposited in large natural 'sinks.' In this study, therefore, soil erosion is presumed to equal zero for all soil types subject to high rates of deposition. For all other areas the USLE predictions are used directly. The mechanics of this adjustment are described in more detail in Annex B.

measurements carried out in neighboring countries. The rates of soil erosion estimated in this study fall within the range of such measurements.

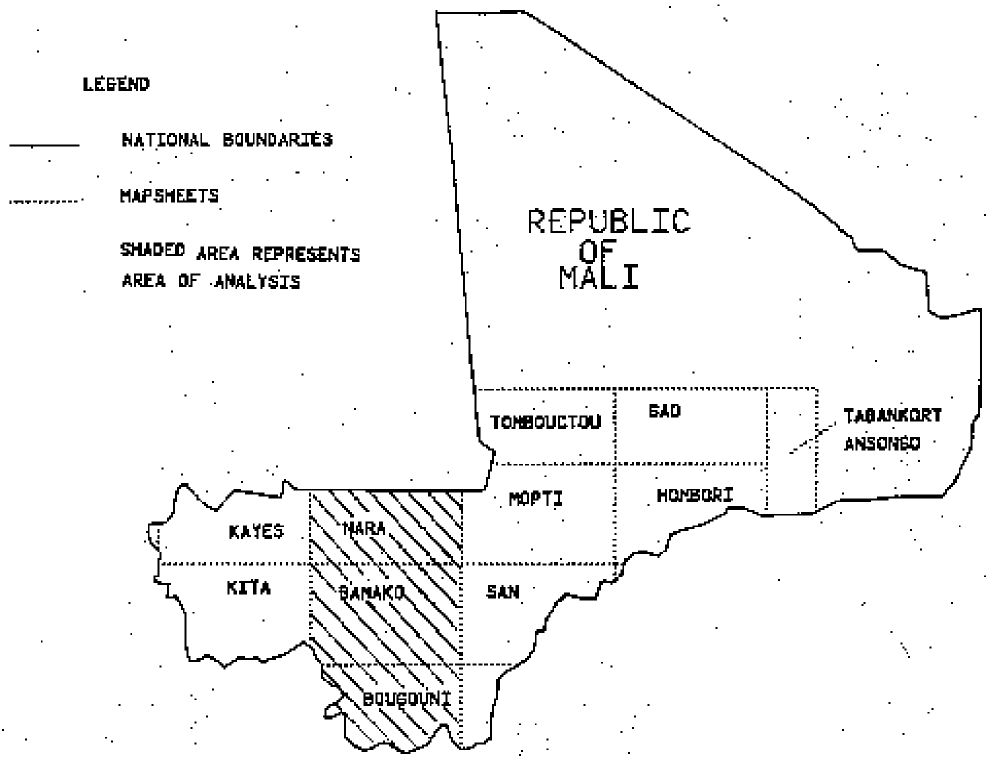
Recall from Chapter 2 that the USLE predicts average annual soil loss (A), in tons per hectare, as a function of five composite variables: the erosivity of rainfall (R), the inherent susceptibility of the soil to erosion by water (K), a combined slope length and steepness factor (SL), crop cover and soil management (C), and a correction factor for 'supplemental' conservation practices (P). For each of these variables, a range of values is established approximating the variation in climate, soil, topography, and land use encountered in Mali.

### 4.4.1 Physical data and area of study

Information on soil resources, vegetation, rainfall and land use in Mali is contained in an atlas prepared from satellite images (Tippetts, Abbett, McCarthy and Stratton 1983). Comprising a set of maps at a scale of 1:500,000 and extensive supporting documentation, the atlas also identifies land capability, the potential for water resources development and other information not used here. The atlas is described further in Annex C.

The TAMS atlas contains three types of maps: soil and vegetation, rainfall and groundwater, and land use. The area covered by the maps (582,778 km$^2$) accounts for 47% of Mali's total surface area, and all of the country's arable land. That part of Mali receiving less than 200 mm mean annual precipitation is not covered. The mapped area is divided into eleven sections, or map sheets (Figure 4.1). For this study we analyse three map sheets (NARA, BAMAKO & BOUGOUNI), covering 32% of the total TAMS study area. The three maps run North to South, providing a representative slice of the major agro-climatic zones of Mali.

Figure 4.1



Using a geographic information system (ARCINFO), the three different types of map for each of the three map sheets were digitized and overlaid. This allowed the identification of 1,281 'map units,' each characterized by a unique combination of surface area, soil type, topography, rainfall and land use. These characteristics were then translated into the five variables of the USLE, based on parameter values estimated empirically in previous studies in West Africa. The average annual rate of soil loss on cultivated land is then calculated for each map unit. The estimation procedure for each of the five variables in the USLE is described in the following sections.

### 4.4.2 Rainfall erosivity (R)

Attempts to define the erosivity of rainfall in West Africa have been very localized. In every case, erosivity has been found to vary widely from one year to another, following swings in the level of annual precipitation.

On a broader scale, Delwaulle (1973) proposes a bivariate linear equation to predict rainfall erosivity (R) throughout the Sahel, based on an econometrically derived relation. Delwaulle's equation, however, requires data on the maximum intensity of rainfall, which few meteorological stations have collected. Roose (1977) argues that the ratio between climatic erosivity and the depth of annual precipitation is always about 0.50 in West Africa, except for seaside and mountain regions. Drawing on rainfall levels recorded over 20 to 50 years at widely spaced stations, Roose derives a multiplier of 0.45 for the Ivory Coast savanna, with two distinct rainy seasons, and 0.55 for the Sudanian and Sahelian steppe, with one annual rainy season.

The two methods of estimating rainfall erosivity yield roughly comparable results (within 10%). Roose's estimates are generally higher than Delwaulle's, possibly reflecting the fact that the latter uses precipitation records from a period of low rainfall, relative to long-term levels.

For this analysis Roose's approach is adopted; a constant coefficient of 0.55 is used to calculate rainfall erosivity (R) for each map unit, based on average annual precipitation. The entire study area is thus divided into fourteen classes of climatic erosivity, corresponding to the precipitation isohyets provided in the TAMS atlas. Estimated values of R vary between 250, in the North, to 800 near the Guinea border. Given the rough equivalence of the other USLE variables throughout the study area, most of the variation in predicted soil loss reflects differences in climatic erosivity.

### 4.4.3 Soil erodibility (K)

The TAMS atlas provides only a qualitative indicator of soil erodibility for each of 68 land classes. This relative ranking incorporates both inherent soil erodibility and average slopes. Any assignment of numerical values to this ranking for use with the USLE model must be somewhat arbitrary, and will not reflect inherent soil erodibility where slopes are steep. For lack of better information, however, the qualitative rankings contained in the atlas are used as a relative index of inherent soil erodibility (K), independent of slope. Numerical values of soil erodibility are derived from published studies of soils in West Africa (Table 4.1).

Table 4.1 Soil erodibility factor (K)

| K value | Location | Source |
|---|---|---|
| 0.004 - 0.137 | Humid and sub-humid tropics | Lal 1983 |
| 0.23 - 0.27 | Burkina Faso (B.F.) | Fauck 1978 |
| 0.04 - 0.17 | Sefa, Senegal | Charreau 1974 |
| 0.05 - 0.32 | Gampela, B.F. | CTFT 1979 |
| 0.06 - 0.20 | Saria, B.F. | CTFT 1979 |
|  | Ferruginous tropical soils from granite (B.F. and Côte d'Ivoire): | Roose in Boodt and Gabriels (eds.) 1980 |
| 0.01 - 0.03 | · gravelly soils (self-mulching) |  |
| 0.03 - 0.15 | · after clearing old fallow |  |
| 0.20 - 0.30 | · after 3-4 years cultivation |  |

For soils of "low" erodibility, as defined by the TAMS atlas, a value of 0.05 is used; for "medium" erodibility: 0.15; and for "high" erodibility: 0.25. Where individual map units include soils of varying erodibility, the value of (K) for the unit as a whole is calculated as a weighted average of the different (K) values assigned to each of the soil types on which cultivation typically occurs. The weights on each soil type reflect not only the prevalence of that type in the map unit, but also the frequency with which each soil type is used for cultivation. Thus land which is grazed, as well as cultivated, or land only occasionally cultivated, is weighted less than land used only for agriculture. The weights are 25% for "occasional" cultivation, 50% for cultivation with "long fallow," 75% for land used for both farming and as pasture, and 100% for land used only for cultivation.

Values for (K) are also weighted by the density of clearing and cultivation in each map unit, based on the findings of Roose (1980) and Lal (1983) that soil erodibility increases after land clearing, due to a decrease in organic matter content and a decline in the structural stability of the soil. The TAMS atlas identifies four categories of land use density, refering to the percentage of cleared or cultivated land within a map unit. Where that proportion is between 30 and 60 percent, (K) is multiplied by 1.5; where density is above 60% cleared or cultivated, (K) is multiplied by 2.0. The resulting values of soil erodibility used in the model range between zero and 0.301, with a mean value on cropland of 0.064.[15]

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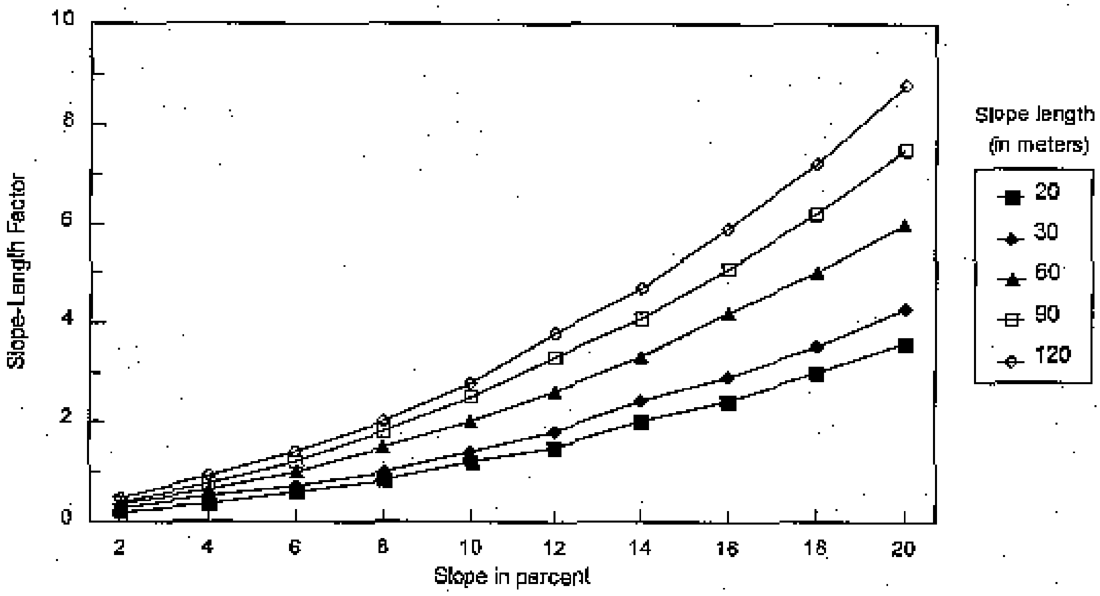
[15] The same procedure was used to calculate the erodibility of all soil types identified in the atlas, independent of whether they are cultivated. This results in a slightly higher average value of 0.10, which is fairly constant across the study area. In other words, cultivation occurs mainly on soils of relatively low inherent erodibility.

### 4.4.4 Slope length (SL)

This variable is calculated in much the same way as soil erodibility. Only cultivated soil units are considered, and slope values are weighted both by the relative importance of the soil type in each map unit and by the relative frequency of cultivation. From the range of gradients given for each soil type in the TAMS atlas, the minimum value was used. A short slope length is assumed (22.12 meters), based on the recommended benchmark value for West Africa (Centre Technique Forestier Tropical 1979). Both procedures tend to bias the estimates of soil loss downward (Figure 4.2). Slopes on regularly cultivated land in the study area rarely exceeded 6%, while the weighted average slope is only 3%. The corresponding slope length values range from zero to 0.76, with a mean of 0.28.

**Figure 4.2 Slope length factor (SL)**



### 4.4.5 Crop cover and soil management (C)

The TAMS atlas identifies three major crops grown in each land use map unit. For each crop a value is assigned representing the average crop cover factor during the growing season, based on data from previous field studies in West Africa (Table 4.2). For comparison, the table includes representative crop cover values (C) for other types of ground cover, such as rice, fallow, and forest. Note that the benchmark value on a bare plot is equal to one.

Table 4.2 Crop cover and management factor (C)

| Crop cover | Fauck (1978) | Techniques Rural en Afrique (1969) | Greenland and Lal (1977) | Singh et al. (1985) |
|---|---|---|---|---|
| Traditional millet or sorghum | 0.4 - 0.9 | 0.6 - 0.8 | 0.3 - 0.9 | |
| Peanuts | 0.4 - 0.8 | | 0.4 - 0.8 | |
| Cotton | 0.5 - 0.7 | | 0.5 | |
| Fallow | | 0.3 | | |
| Prairie in good condition | 0.01 | | 0.01 | |
| Prairie burned or over-grazed | 0.1 | | | |
| Dense forest | | | 0.001 | |
| Bare plot | | 1.0 | | |
| Cowpea | | | | 0.28 |
| Maize | | | | 0.42 |
| Rice (paddy) | | | | 0.28 |

Values used in this study are as follows: for millet, sorghum, peanuts, and cotton, C = 0.6. For maize, C = 0.42, and for cowpea C = 0.28. These are average values, as the crop cover factor varies during the growing season, mirroring the degree to which foliage protects the soil from the erosive effects of rainfall. The final value for each map unit is a weighted average of values for each of the three major crops, using arbitrary weights of 50, 30 and 20% for the first, second and third crop, respectively. Since the first and second crop in almost all map units where cultivation occurs and where there is no significant soil deposition is either millet or sorghum, the final values all cluster around 0.6.

### 4.4.6 Conservation practices (P)

The USLE allows for conservation practices such as contour plowing, mulching, or terracing. The benchmark value of 1.0 refers to conventional plowing executed perpendicular to the slope of the field. Sample values of (P) are presented in Table 4.3, using data from Burkina Faso, Ivory Coast, Senegal and Niger.

For this study an arbitrary value of 0.8 is used in areas where annual rainfall is above 600 and a value of 0.6 is used elsewhere. The distinction is based on the fact that farmers in less humid areas typically do not till their mostly sandy fields, but sow directly into small pockets. As they do not disturb the surface crust, there is subsequently less soil loss. Farmers in more humid zones, on the other hand, are obliged to turn the soil completely in order to reduce weeds. The majority of the farmers in the study area till by hand, leaving no channels for runoff.

Table 4.3 Supplemental conservation practices (P)

| Conservation practice | Roose (1977) | Techniques Rurales en Afrique (1969) |
|---|---|---|
| contour trench (tied ridges) | 0.1 - 0.2 | |
| strip cropping | 0.1 - 0.3 | 0.3 - 0.45 |
| straw mulch | 0.01 | |
| dry stone ridges | 0.1 | |
| grass fallow | 0.1 - 0.5 | |
| contour plowing | | 0.6 - 0.9 |
| terraces | | 0.3 - 0.9 |

### 4.4.7 Estimated soil erosion (A)

Using the data described above, estimates of soil erosion on Malian farms in the study area were generated for each map unit. The results are presented in maps in Annex D. Estimated soil loss on cultivated land averages only 1 ton per hectare per year, in the North, but over 10 tons/ha/yr, on average, in the far South. For the study area as a whole, the average estimated soil loss is 6.5 tons/ha/yr.

Empirical measurements of soil erosion were not available for Mali when the study was conducted. Hence it was not possible to verify directly the soil loss predictions obtained with the USLE. However, the estimated values for Mali are comparable to data obtained from erosion plots in neighboring West African countries, under a similar range of conditions (Table 4.4).

The highest rates of estimated erosion in Mali (31 tons/ha/yr) occur in southern-most areas and result from both relatively high rainfall, and somewhat higher values for soil erodibility (K). The latter may be attributed to the greater density of cultivation in the area, which in turn probably reflects relatively high population densities. Although the maximum estimated annual soil loss exceeds the highest rate cited in Table 4.3, it is still low compared to measured erosion at some stations in Côte d'Ivoire, which have recorded losses over 500 tons/ha/yr (Roose 1986).

**Table 4.4 Measured soil loss under traditional cultivation in West Africa**

| Country | Station | Source | Mean Rainfall (mm) | Slope (%) | Mean Erosion (tons/ha/yr) | |
|---|---|---|---|---|---|---|
| | | | | | Crop | Fallow[1] |
| Nigeria | Ibadan | Lal (76) | 1282 | 1 | 0.7 | |
| | | " | 1282 | 5 | 3.5 | |
| | | " | 1282 | 10 | 3.4 | |
| | | " | 1282 | 15 | 13.9 | |
| Senegal | Sefa | CTFT (79) | 1200 | 1.5 | 7.5 | 4.9 |
| Ghana | Nyankpala | Bonsu (81) | 1082 | 2 | 0.2 | |
| Burkina | Ouagadougou | Charreau (72) | 850 | .5 | 4.3 | 0.08 |
| | Gampela | Roose (84) | 731 | .8 | 4.1 | |
| | Gonsé | " | 691 | .5 | | 0.15 |
| | Saria | " | 643 | .7 | 6.0 | 0.50 |
| | " | " | 850 | 1.7 | 7.3 | 0.17 |
| | Linoghin | " | 636 | 1.3 | | 0.80 |
| | Sirgui | Koutaba (86) | 692 | .08 | 7.3 | 5.7 |
| C. Ivoire | Divo | Roose (86) | 1550 | 10 | | .43 |
| | Bouake | " | 1200 | 4 | 13.0 | .05 |
| | Korhogo | " | 1350 | 3 | 4.0 | .11 |
| Niger | Kountkouzout | Vuillaume (82) | 450 | 1 | 1.4 | |
| | " | " | 450 | 3 | 12.7 | 6.4 |
| | " | " | 450 | 12 | 17.0 | 9.9 |
| | Allokoto | Delwaulle (73) | 440 | 3 | 9.5 | |
| MEAN: | | | 920 mm | 4 % | 6.8 t | 2.4 t |
| STANDARD DEVIATION: | | | 362 mm | 4 % | 4.9 t | 3.4 t |
| MAXIMUM: | | | 1550 mm | 15 % | 17.0 t | 9.9 t |

1/ Secondary regrowth following cultivation; grass savannah in most cases.

## 4.5 The Effect of Soil Erosion on Crop Yields

To assess the economic impact of erosion, tons of soil loss per hectare per year may be translated into foregone net farm revenue that would have been earned if the soil had stayed put. Of course, crop yields are a function of many variables, of which soil fertility is just one. Furthermore, physical soil loss is only a rough proxy for declining fertility. It may also be offset by organic or chemical fertilization, or other soil management techniques. Nevertheless, in side-by-side experiments which attempt to control for other variables, it appears that loss of top soil has a measurable and generally negative effect on crop yields (see Section 2.2).

Little empirical research on the relation between soil erosion and crop productivity has been conducted anywhere in Africa. However, one model of the erosion-yield relation has been developed by the International Institute for Tropical Agriculture (IITA) in Ibadan, Nigeria (Lal, 1981). The effect of cumulative soil loss on crops under continuous cultivation was estimated econometrically, by comparing maize and cowpea yields on side-by-side plots under varying levels of natural soil erosion.

Both southern Mali and south-western Nigeria share soils of poor inherent fertility, weak structure, and low erodibility (Lal 1987a). The two countries are also both characterized by an erosive climatic regime, with intense, highly variable rainfall. It is assumed that crop yields in Mali are *no less* sensitive to soil loss than they are in Nigeria, although actual rates of erosion may vary. The model itself consists of a simple exponential relation, as follows:

$$Y = C_{e}^{-\beta x}$$

where:
$Y$ = yield in tons per hectare
$C$ = yield on uneroded (newly cleared) land
$e$ = the natural log (2.718282)[16]
$\beta$ = coefficient varying with crop and slope
$x$ = cumulative soil loss in tons per hectare

The form of the equation implies that incremental yield losses will gradually decline with cumulative erosion. This conforms to the intuition that crops will be relatively intolerant of initial soil losses, due to the shallow fertile horizon of the soils studied. Lal estimated eight equations, one for each crop and four slopes (1, 5, 10, and 15%). The estimated coefficients ($\beta$) varied between 0.002 and 0.036 for cowpea, and between 0.003 and 0.017 for maize. All but one of the Beta coefficients relating yield to soil loss are significant to at least 5%.

For the Mali study, the IITA model is applied uniformly to all crops and in all regions. Because both crops and yields are different in Mali, however, the variable C is dropped and the following equation:

$$\hat{Y} = 1 - e^{-\beta x}$$

is used to calculate a *percentage* change in yield ($\hat{Y}$), for every level of soil erosion. Of course, crop yields are probably not equally sensitive to soil loss across all of Mali. Yield response may vary by crop, soil type, rainfall, and other factors. Unfortunately, the available data base does not support such distinctions. However, by varying the exponential coefficient ($\beta$) a range of yield penalties may be derived, which are assumed to bracket the true impact of soil loss. Four coefficients are used: $\beta$ = 0.004, 0.006, 0.010, and 0.015, all of which lie within the range of values estimated by IITA. Figure 4.3 shows the change in yield incurred for each of these coefficients, for various levels of cumulative soil loss.

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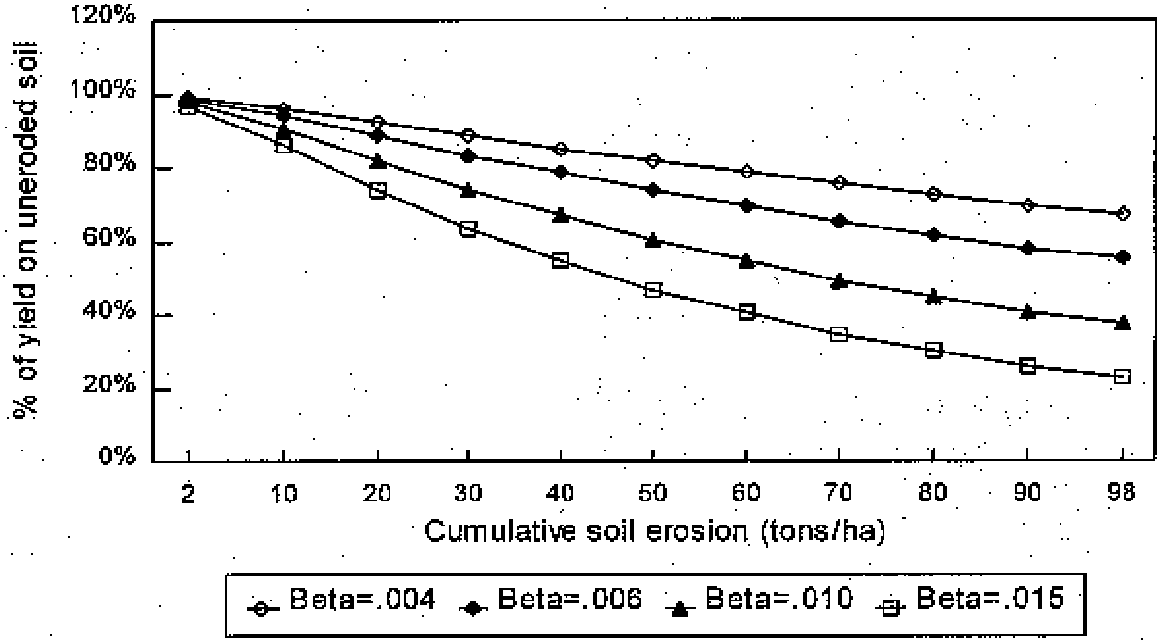
[16] An earlier publication of these results (Bishop and Allen 1989) inadvertently omitted the constant $e$. This is the correct version of the model, as reported by Lal (1981).

**Figure 4.3 The effect of soil erosion on crop yields**
for a range of regression coefficients (Beta)



Source: Lal 1981

Note that the functional form of the erosion-yield equation implies a *constant elasticity* relation between cumulative soil loss and yield. In other words, the percentage yield loss in the first year is exactly the same as the percentage loss in the tenth year, assuming a constant rate of erosion. It is enough to know the annual rate of soil loss and mean current yields to estimate current crop losses.

One way to check the yield penalties estimated using Lal's equation is by comparison with measured yield trends under continuous cultivation. Experiments carried out in Kano, Nigeria, between 1931 and 1955, provide average annual yields for groundnut, millet and sorghum, with and without manure, under continuous cultivation from clearing (Nye and Greenland, 1960). We assume that over 24 years of measurement, annual climatic variation cancels out, so these figures are taken to reflect both soil erosion and exhaustion of soil nutrients (Table 4.5).

It would be curious if annual changes in yield estimated using Lal's regression equation were much greater than the highest annual rate of yield decline measured at Kano, for all crops (i.e. 9.9%). In practice, mean estimated yield penalties only exceed this level when Beta is assigned a value of 0.01 or higher, and then only for lands in the far south of Mali. The average yield penalty for the BOUGOUNI map sheet, for example, is about 16.5% when Beta equals 0.015. One may argue, on the other hand, that today's soil is less capable of sustaining yields, after decades of increasingly intense exploitation and the extension of cultivation to less fertile, marginal lands. This interpretation is supported by more recent studies of continuous cropping in West Africa, one of which shows maize yields dropping by an average of 43% per year, over four years (Sobulo and Osiname, 1986).

**Table 4.5 Declining crop yields under continuous cultivation**

| Year | Groundnut | | Millet | | Sorghum | | Mean percent change per year | |
|---|---|---|---|---|---|---|---|---|
| | w/o | w/ | w/o | w/ | w/o | w/ | w/o | w/ |
| 1931 - 35 | 1015 | 1283 | 922 | 1164 | 543 | 1141 | | |
| 1936 - 40 | 784 | 1126 | 455 | 836 | 328 | 1014 | - 9.2 | - 3.8 |
| 1941 - 45 | 698 | 1015 | 318 | 658 | 105 | 942 | - 9.9 | - 2.8 |
| 1946 - 50 | 323 | 634 | 546 | 1053 | 91 | 935 | - 2.3 | + 0.3 |
| 1951 - 55 | 511 | 848 | 330 | 864 | - | - | + 0.4 | - 0.9 |
| Total decline (%) | 50 | 34 | 64 | 26 | 83 | 12 | | |

Note: All yield figures are in metric tons per hectare. (w/o) designates plots cultivated without manure; (w) designates plots receiving 6.7 tons/ha manure each year.
Source: Nye and Greenland, 1960.

## 4.6 From Crop Yields to Farm Income

The relation between crop yields and farm income is not strictly proportional. A decline in yield, for example, may result in a more than proportionate fall in farm income, due to the inflexibility of certain fixed costs. Likewise, an increase in yield will entail some additional effort for weeding, harvesting, and storage, but because many input costs are fixed, the percentage increase in farm income may exceed the percentage yield increase.

Crop budgets may be used to capture these effects when valuing yield losses. Budgets used in the model are from the International Crops Research Institute for the Semi-Arid Tropics (ICRISAT) as reported by Matlon and Fafchamps (1988). They were derived from studies of village farm land in Burkina Faso which had been continuously cultivated for about ten years, on average. Soils, climate, production systems, and prices are all comparable to those of Mali. The farm budgets include 21 crop combinations in 3 climatic zones.

Seven crop combinations are used here, corresponding to the major crops identified in the TAMS atlas. These are: millet, millet with cowpea, sorghum, maize, cotton and groundnut. Rice is excluded from the analysis as virtually all of it is grown on seasonally flooded lands which do not suffer significant net soil loss. Moreover, the ICRISAT budgets are condensed to distinguish just five components: crop value, fixed capital inputs, fixed labor, variable labor and returns to land. All values are expressed in terms of 1983 CFA francs per hectare. The condensed budgets are listed in Annex E.

For each of the three major crops found in every map unit, the economic impact of yield foregone due to estimated soil erosion is calculated as follows:

1) apply the percentage yield foregone, estimated from the regression equation, to the gross value (per hectare) of the harvest of each crop;

2) apply the same proportion to that part of the labor input that is a function of yield (weeding and harvesting cost per hectare);

3) subtract (2) from (1) to obtain the net revenue foregone for each crop;

4) weight net returns foregone by the relative importance of each crop in the map unit to obtain average net revenue foregone per hectare per year.

The weights used to adjust for crop importance are not constant across the study area. According to Matlon and Fafchamps (1988), in Burkina Faso the relative proportion of the total cultivated surface area occupied by each crop varies according to the agro-climatic zone (Table 4.6). Crop mixes are more diversified in the South, a fact the authors attribute to the greater flexibility offered by more generous climate and soils. Assuming that cropping patterns in the study area are similar to those in Burkina Faso, and generalizing from the figures provided by Matlon and Fafchamps, the foregone income calculated for the first, second and third crops is weighted as follows: N. Guinea zone: 40, 30, and 30%, respectively; Sudanian zone: 60,30, and 10%; Sahelian zone: 90,5, and 5%.

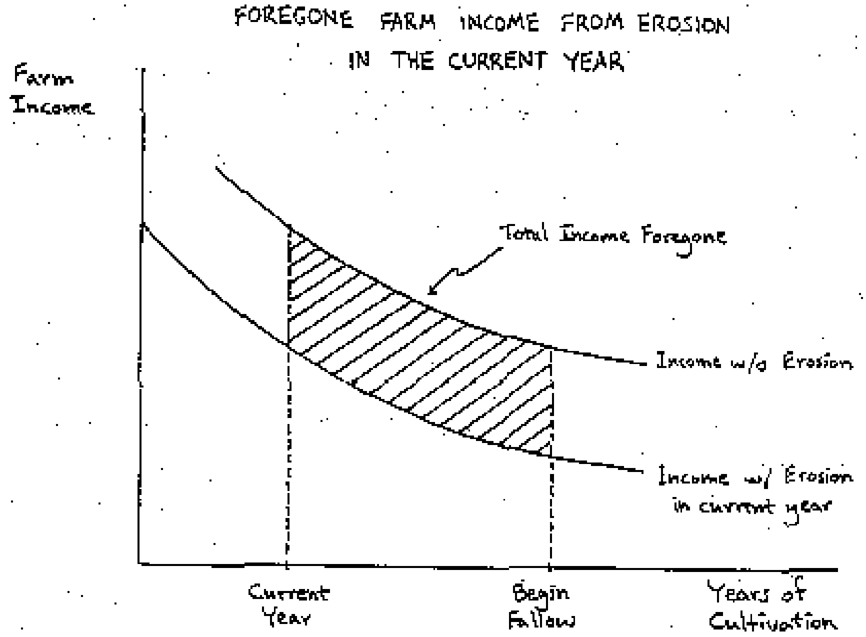
**Table 4.6 Percentage of cultivated land occupied by each crop**

| Agro-climatic Zone | Millet | Sorghum | Maize | Groundnut | Cotton | Other |
|---|---|---|---|---|---|---|
| N. Guinea | 22 | 37 | 5 | 1 | 29 | 6 |
| Sudan | 27 | 60 | 2 | 8 | 1 | 2 |
| Sahel | 93 | 3 | 1 | 0 | 0 | 3 |

Recall that rice is excluded from the calculation of erosion impacts, on the grounds that rice is grown exclusively in natural depressions or on alluvial plains which may incur some soil loss but probably also receive significant sediment deposits. This exclusion only makes a significant different to average losses per hectare in the BAMAKO map sheet, due to the relatively large proportion of land devoted to rice along the Niger River.

The resulting foregone income per hectare, derived from the calculations described above, does not account for the entire economic loss incurred. Land degradation in the current year is presumed to affect yields in future years, even if no further soil loss occurs. In other words, every single instance of soil loss results in a permanent decrease in yield, relative to what would have been obtained otherwise. For the sake of simplicity, it is assumed that the nominal value of this loss remains constant over time.[17] The present value of the stream of foregone income stream is then calculated for various rates of discount and time horizons, assuming that the land is eventually fallowed (Figure 4.4).[18]

**Figure 4.4**



For the base case, assume a conservative discount rate of 10 percent and a moderate time horizon of 10 years until fallowing. Recall that crop budgets are based on 1983 prices. With these assumptions, for the study area as a whole, the mean present value of income foregone over ten years, due to one year of soil loss, ranges between 2 and 8 thousand CFA/ha, for Beta = 0.004 and 0.015, respectively. To put these sums in perspective, note that average net farm revenues, over the entire study area, are about 9,700 CFA/ha/yr (excluding rice).[19]

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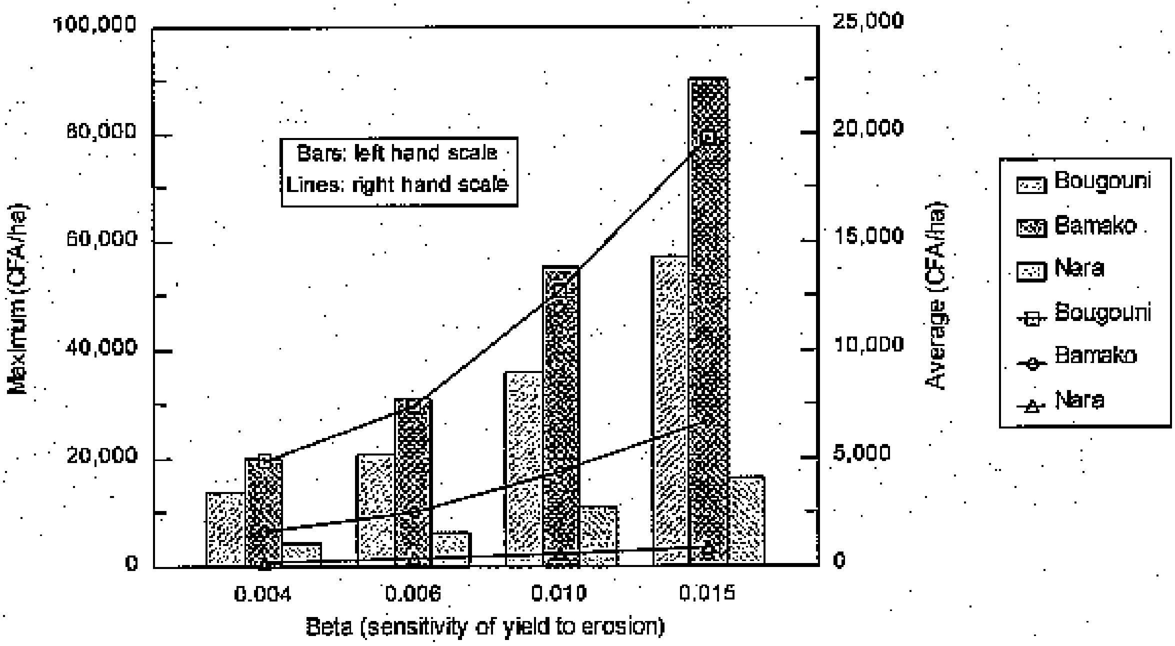
[17] If continuous cropping erodes the productive potential of the soil, even without erosion, and if the form of the relation between cumulative erosion and yield conforms to Lal's description, then annual income foregone due to one year of erosion will actually decline, while remaining constant as a percentage of yield in each year. However, since the yields reported by Matlon and Fafchamps are average values over the entire cropping cycle (from initial land clearing to abandonment), some decline in yield is already implicit.

[18] This assumes complete restoration of soil fertility and crop yields through fallowing. Given the ever shorter duration of fallow periods, this assumption may be too generous. Fallowing may not fully compensate for damage done by erosion, in which case the value of future losses is underestimated. Yields are assumed to decline even without erosion, due to exhaustion of soil fertility by crops. We ignore the likelihood that, without erosion, cultivation would be prolonged.

[19] Gross farm income was estimated using the crop budgets provided by Matlon and Fafchamps and information contained in the TAMS atlas. On the basis of 1979-80 land use data (from TAMS), the total cultivated surface area was estimated at 31,255 km$^2$ (see Annex C). Using the budgets for

Analysis of estimated revenue foregone by agro-climatic zone reveals differences which reflect not only varying levels of soil loss, but also the relative profitability of farming in the North and the South (Figure 4.5). Average erosion losses are greatest in the South, on the BOUGOUNI map sheet, where even modest estimates of average income foregone (Beta = 0.004) are equivalent to 54% of the region's average net returns to dry land farming (9,100 CFA/ha/yr).

**Figure 4.5 Present value of income foregone due to one year of erosion**
(r = 10%, t = 10 yrs., 1983 CFA/ha)



Regional averages, in turn, obscure very high levels of revenue foregone on some map units, especially in central and southern areas (BOUGOUNI and BAMAKO). The highest losses per hectare are found on the BAMAKO map sheet where, for the same assumptions of time preference and time horizon as above, maximum losses reach about 20,000 CFA/ha (Beta = 0.004), for every year of soil erosion. Average net returns to farming, on these same map units, do not exceed 13,000 CFA/ha/yr. These figures imply that net real returns from farming may be negative, on land subject to high rates of erosion, when the value of foregone future yields, due to soil loss, exceeds net farm income in the current year.[20]

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all crops (including rice) an estimate of gross national income from farming was derived by summing up gross farm income in each map unit (i.e. the value of the harvest). The resulting figure, using 1983 prices, is 154 billion Francs CFA. The mean value per cultivated hectare on this basis is 49,272 CFA. Actual income is probably lower, due to the increase in cultivated are between 1980 and 1983.

[20] Note that when the rate of discount exceeds 65% per year, as might well be the case for many poor farmers, the present value of yields foregone over a ten year time horizon will *never* surpass current net income. From such a perspective erosive farming appears profitable even on the most vulnerable lands.

## 4.7 Erosion Losses and the Cost of Conservation

Another way to look at erosion losses is to compare the value of income foregone to the cost of soil conservation measures. The only technologies for which the costs of implementation are comparable to the estimated losses presented above are simple water harvesting and erosion control measures, such as contour plowing, tied ridges, rock lines or contour bunds, and grass strips. More expensive measures, such as terracing, do not appear to be justified by the level of losses resulting from soil erosion in the study area. Data are taken from three cost-benefit analyses of a relatively inexpensive water harvesting and erosion control method promoted in Mali (CILSS 1988) and in Burkina Faso (CILSS 1988, Matlon 1985). The studies evaluated the use of rock lines along contours (combined with grass strips in Mali), in terms of capital and maintenance cost, and the benefits of increased crop yields.[21]

Relative to yields on adjacent untreated plots, various authors cite increases from 9% to 90% due to the use of rock lines along contours in Burkina Faso (Table 4.7). These benefits reflect not just the conservation of soil on-site, but also increased moisture availability due to reduced runoff, and possibly deposition of fertile sediments from land above the treated plots. According to Matlon (1985), the benefits of increased water availability will dominate the effects of erosion control, where rainfall is scarce. No attempt is made to quantify the magnitude of such additional benefits here, although clearly they will make any technology more attractive.

**Table 4.7 Yield benefits of water harvesting measures (relative to adjacent untreated plots)**

| Technique employed | Yield benefit (%) | Source |
|---|---|---|
| stone bunds (farmers) | 12 - 90 | Reij et al. 1988 |
| rock bunds (farmers) | 59 | " |
| 'diguettes en pierre' | 40 | Critchly & Reij 1987 |
| rock ridges | 35 | CILSS 1988 |
| rock bunds (station) | 9 - 40 | Matlon 1985 |

In their estimates of the cost of rock lines, the three analyses cited above report a single capital investment, ranging from 21,500 to 30,000 Francs CFA/ha (in 1985 prices). All three also report indefinite annual maintenance costs ranging from 2.5% to 33% of the initial investment. They determine the present value of those costs, over fifteen and twenty year time horizons, using discount rates of 15% and 10%. These figures are easily normalized to a ten year time horizon and 10% discount rate, as in Table 4.8.

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[21] Water harvesting is virtually synonymous with soil conservation. Both aim to reduce runoff from rainfall, the primary cause of soil erosion.

**Table 4.8 Present cost of soil conservation measures**
(r = 10%, t = 10 yrs., 1985 Francs CFA/ha)

| Technique and location | Present Cost (PV) | Source |
|---|---|---|
| horizontal rock ridges (Burkina Faso) | 47,300 | CILSS 1988 |
| rock lines and grass strips (Mali) | 69,100 | " |
| rock bunds: 30,000 CFA/ha with 10% maintenance (Burkina Faso) | 47,300 | Matlon 1985 |
| rock bunds: 21,525 CFA/ha with 7% maintenance (Burkina Faso) | 30,200 | " |

Note that these capital costs cover only the outlay by farmers, in the form of dry season labor. Funds spent by governments and foreign agencies, to teach and encourage farmers to adopt the technology, are excluded. Some information on the latter comes from Wright (cited in Reij, Mulder and Begemann 1988), who estimated administrative costs per hectare treated, for a program in Burkina Faso. Even there, the salary of government agents was excluded, as was the depreciation of the project's capital equipment.

Wright's figures are nonetheless instructive. He estimated project costs at 771,400 CFA/ha in 1981, declining to 17,300 CFA/ha in 1985, and 8,510 CFA/ha in 1986 (assumed to be nominal amounts). Assuming that only one year of average project expenses would be charged to each hectare treated, and taking the lowest capital cost figure from Table 4.8, the minimum average cost of the technology may be estimated at about 40,000 CFA/ha (30,200 + 8,500). Assuming slightly higher administrative and capital expenditure, the estimated cost rises to 65,000 CFA/ha (47,300 + 17,300). Finally, for the first years of a project, total costs will exceed 100,000 CFA/ha.

In comparing these costs of conservation to the estimates of foregone farm income, one more adjustment is required.[22] Figure 4.5 shows the present value of income foregone due to erosion in the current year only. In comparing erosion losses to conservation costs, it is important to consider losses that occur in every year of the time horizon, until fallowing. With a ten year horizon, for example, gross losses include the present value of foregone future income attributable to erosion in the current year, plus the present value of all losses resulting from erosion in the following year, and so on for ten years (Figure 4.6).[23]

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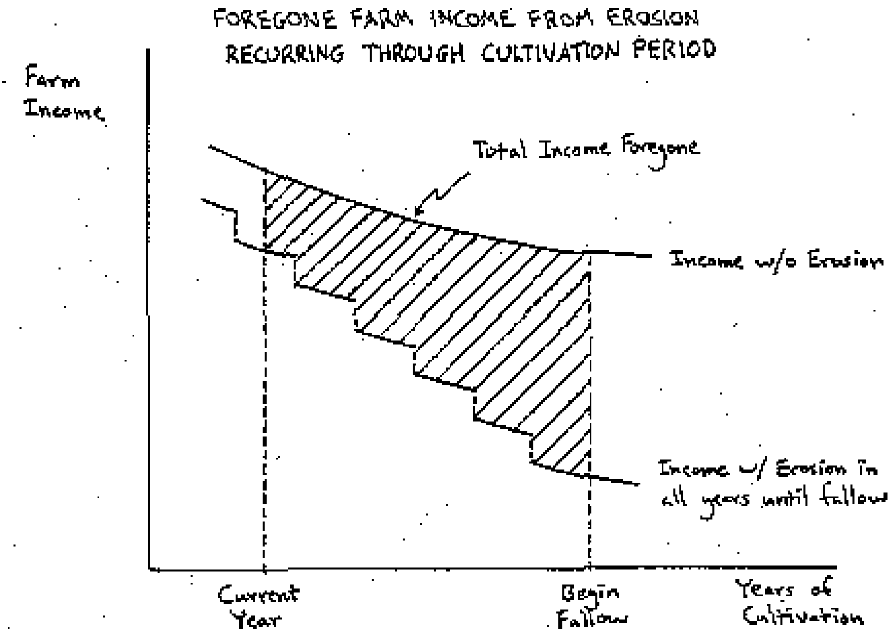
[22] Note that the value added deflator for agriculture in Mali was 96.4 in both 1983 and 1985, hence it was not necessary to adjust the crop budgets for price changes (World Bank 1994).

[23] As above, we ignore the likelihood that cultivation would be prolonged, without erosion, and thus underestimate the value of total losses.

Figure 4.6



After allowing for recurring soil loss, and using the assumed 10% discount rate and 10 year time horizon, it is relatively easy to identify map units where the present value of foregone net farm revenue, due to erosion, exceeds the cost of installing and maintaining rock lines along contours. These are shown on maps presented in Annex F, assuming the lowest cost of installing and maintaining rock lines, for a range of assumptions about the impact of erosion on crop yields (Beta). In principle, these are areas where yield losses due to erosion may justify conservation efforts. By varying the magnitude of the impact of soil loss (Beta), it is possible to establish a priority ranking of areas which merit attention.[24]

The information is summarized in Figure 4.7, which also shows the effect of varying the cost of conservation (see Annex F for more detail). The figure presents the number of map units where erosion losses exceed the cost of conservation, as well as the total cultivated surface area.[25] For example, if the impact of erosion on crop yields is moderate (Beta = 0.006) and it costs 65,000 CFA, in present value terms, to install and maintain contour bunds over 10 years, then the model identifies 48 map units, with a cultivated surface area of about 70,000 hectares, where the present value of net farm income foregone over the same period exceeds the cost of the bunds.

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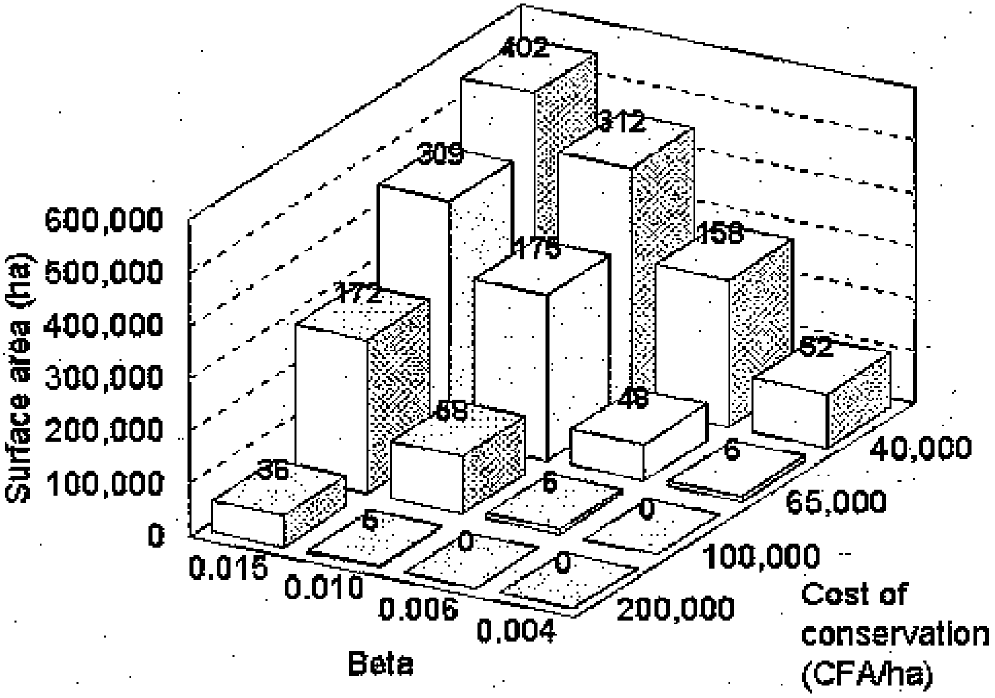
[24] It is assumed that contour bunds are 100% effective in halting net soil loss. Relaxing this assumption would reduce the number of map units where foregone income exceeds the cost of conservation, without altering their distribution. Increasing the assumed cost of conservation has the same effect.

[25] A uniform crop-fallow ratio of one-to-one is assumed. In other words, 50% of the land identified as cleared or cultivated in the TAMS atlas is presumed to be sown in any year. Potential future income lost as a result of erosion on fallow land is disregarded.

**Figure 4.7 Surface area where erosion losses exceed the cost of conservation**
(r = 10%, t = 10 yrs., 1985 Francs CFA)



Note: number of map units at top of each column

Note that this method of distinguishing map units depends critically on the choice of a discount rate. Since the largest cost component of soil conservation occurs in the initial year, while the cost of erosion is spread out over the entire cropping cycle, a lower discount rate would increase the number of map units with losses exceeding the cost of conservation.

Of course the greatest losses occur where there is a combination of relatively steep slopes, high rainfall, and dense cultivation. Assuming that soil loss has a large impact on yields (Beta = 0.015), there are 36 map units, with a total of 59,783 cultivated hectares, where losses exceed 200,000 CFA/ha over ten years. These map units are all situated in what Matlon and Fafchamps call the Sudanian zone, where traditional farming is most profitable.[26]

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[26] The proportion of land cleared or cultivated on these map units is between 31 and 60%, higher than the average agricultural density over the entire study area (about 20%) but below the maximum density reported by TAMS (category 4: > 60%). The principal crops in these map units are sorghum and millet, typical for the region.

## 4.8 The Cost of Soil Erosion at a National Level

The final component of the analysis is to evaluate the cost of soil erosion to the Malian economy as a whole. The simplest approach is to add up annual losses in each map unit, extrapolate to areas outside the study zone, and thereby derive the total value of net farm income foregone due to erosion nation-wide. This is the first method used. A more sophisticated analysis is also illustrated, based on estimates of the marginal benefit and marginal cost of soil conservation. Using the latter method, it is possible to evaluate the proportion of foregone income that represents excessive soil erosion and a real loss of welfare, and derive the level of adjustment to be made to current national income (GDP).[27]

The results presented so far are based on analysis of just three of eleven TAMS map sheets: Bougouni, Bamako and Nara (see Figure 4.1). In estimating losses on a national scale, it is assumed that these map sheets are representative of the rest of Mali. For each map unit, weighted average net revenue losses per hectare are multiplied by the total surface area of the map unit and by the relative density of farming. Summing over all map units yields the total loss. To account for the varying levels of losses occurring in different agro-climatic zones, the northern and southern halves of each map sheet are aggregated separately.

Extrapolation to the national level simply involves extending total losses, estimated for each of the six sub-map sheets, to comparable regions. The TAMS atlas provides the surface area of map sheets not analyzed here, over which we extrapolate the total losses estimated for each sub-map sheet. An adjustment is made for the inland delta of the Niger River, a vast floodplain where little erosion occurs.[28]

Table 4.9 presents foregone farm income resulting from an average year of soil erosion, under the most conservative assumptions of the impact of soil loss on crop yields (Beta = 0.004), and with the same assumed time horizon and time preference used above (ten years until fallowing, 10% discount rate). Total estimated losses under these assumptions are 9.3 billion Francs CFA, or about 1.5% of 1988 GDP.[29]

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[27] Both approaches ignore the possible price effects of increased agricultural production, if erosion did not occur.

[28] After adjusting for the inland delta, the study zone accounts for about half of the arable surface area presumed subject to erosion in Mali.

[29] Estimated losses are compared here to 1988 GDP, rather than using 1985 prices as above, mainly in order to avoid the distorting effect of the US Dollar exchange rate, which was unusually high in 1985 (449 CFA/$ as opposed to an average of 325 CFA/$ between 1980 and 1991). Price inflation in the agriculture sector was about 3.7% between 1985 and 1988 (World Bank 1994).

**Table 4.9 Estimated annual nation-wide foregone farm income**
(r = 10%, t = 10 yrs., Beta = 0.004, est. 1988 prices, US$1 = 298 CFA)

| Map Sheet | One Year Map Sheet Loss (CFA millions) | Comparable Surface Area (Multiplier) | One Year National Loss (CFA millions) |
|---|---|---|---|
| Bougouni (South) | 242 | 1.25 | 303 |
| Bougouni (North) | 154 | 1.25 | 192 |
| Bamako (South) | 159 | 2.83 | 451 |
| Bamako (North) | 91 | 3.48 | 318 |
| Nara (South) | 25 | 3.50 | 88 |
| Nara (North) | 6 | 4.35 | 25 |

| | US Dollars (Millions) | Francs CFA (Millions) | % Mali GDP* | % Agric. GDP** |
|---|---|---|---|---|
| Nationwide annual income losses on farm land | 4.62 | 1,377 | 0.22 | 0.50 |
| Discounted present value foregone farm income | 31.21 | 9,301 | 1.51 | 3.38 |

Notes: * 1988 = 615.8 Billion CFA
** 1988 = 275.3 Billion CFA (farming, forestry, fishing and livestock)

Finally, in order to determine what proportion of total farm revenue foregone due to soil erosion represents a real loss of economic welfare we compare the marginal benefit of soil conservation to the marginal cost. Recall that the cost of conservation was calculated above as 40, 65 or 100 thousand CFA/ha, depending on administrative expenses and technology. Taking the lowest cost estimate (40,000 CFA/ha) and adopting conservative assumptions of erosion impacts (Beta = 0.004), the model identifies 103,465 hectares of cultivated land in the study zone where foregone income exceeds this cost. When the cost of conservation is assumed to be 65,000 CFA/ha, this figure falls to 9,817 hectares.

These two points permit the construction of a hypothetical marginal benefit curve or, in other words, a demand function for soil conservation in the study zone. Assuming a constant elasticity of conservation with respect to cost, and converting CFA values into their dollar equivalents (at an exchange rate of 298 CFA/US$), the implied marginal benefit function derived from these two points can be expressed as follows:[30]

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[30] The parameters of the equation were estimated using a generalized, non-linear, constant elasticity demand (or marginal benefit) curve. We start with the following equation:

$$Q=kP^{-\varepsilon} \qquad (1)$$

Where: $Q$ equals the area of cultivated land where foregone income exceeds the cost of conservation, $P$ equals the cost of conservation and $k$ and $\varepsilon$ are the parameters we wish to estimate. This equation may be re-written as:

$$P = 1450.92 \times Q^{-0.20615}$$

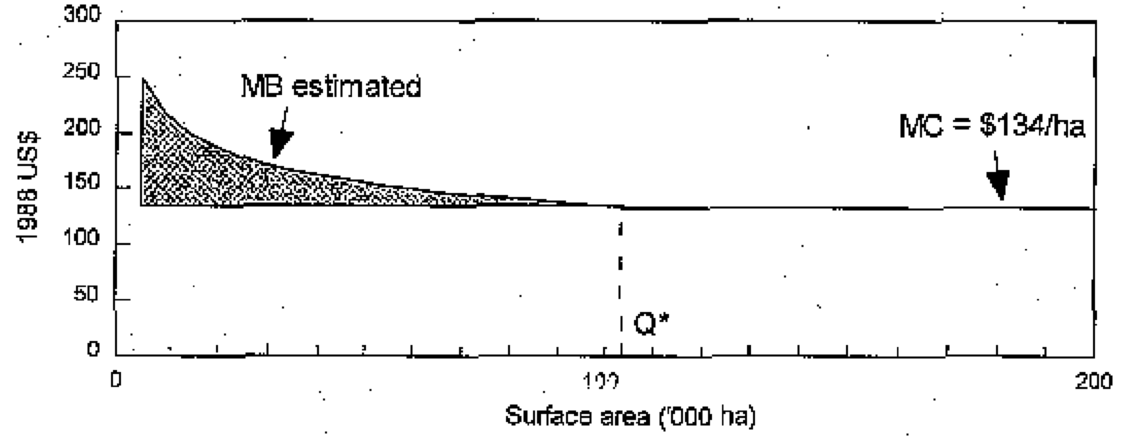
where: P = marginal benefit of conservation, in terms of net farm revenue saved (US$/ha)
Q = number of hectares of farm land affected (ha)

With this marginal benefit curve it is simple to calculate the welfare loss arising from excessive soil erosion in the study zone. Assuming that the current level of soil conservation in Mali is negligible and taking 40,000 CFA/ha (or US$134) to be the constant marginal cost of soil conservation, the shaded area in Figure 4.8 represents the total welfare loss in the study zone. Simple extrapolation as above yields an estimate of the nation-wide loss.

**Figure 4.8**

**Welfare Losses from Soil Erosion in Mali**

Bougouni, Bamako and Nara map sheets only



Note: Beta = 0.004; r = 10%; t = 10 years

The resulting estimated loss of economic welfare due to inadequate soil conservation is about US$7.3 million (2.2 billion CFA). This is equivalent to about 0.35% of GDP (compared to gross losses estimated at 1.5% of GDP in the previous section). On the other hand, if the marginal cost of conservation is assumed to be higher (at $218 per ha) then the corresponding

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$$P = \left(\frac{Q}{k}\right)^{-1/\epsilon} \qquad (2)$$

Substituting $A=(1/k)^{-1/\epsilon}$ and $\alpha=1/\epsilon$ into (2), we obtain:

$$P = AQ^{-\alpha} \qquad (3)$$

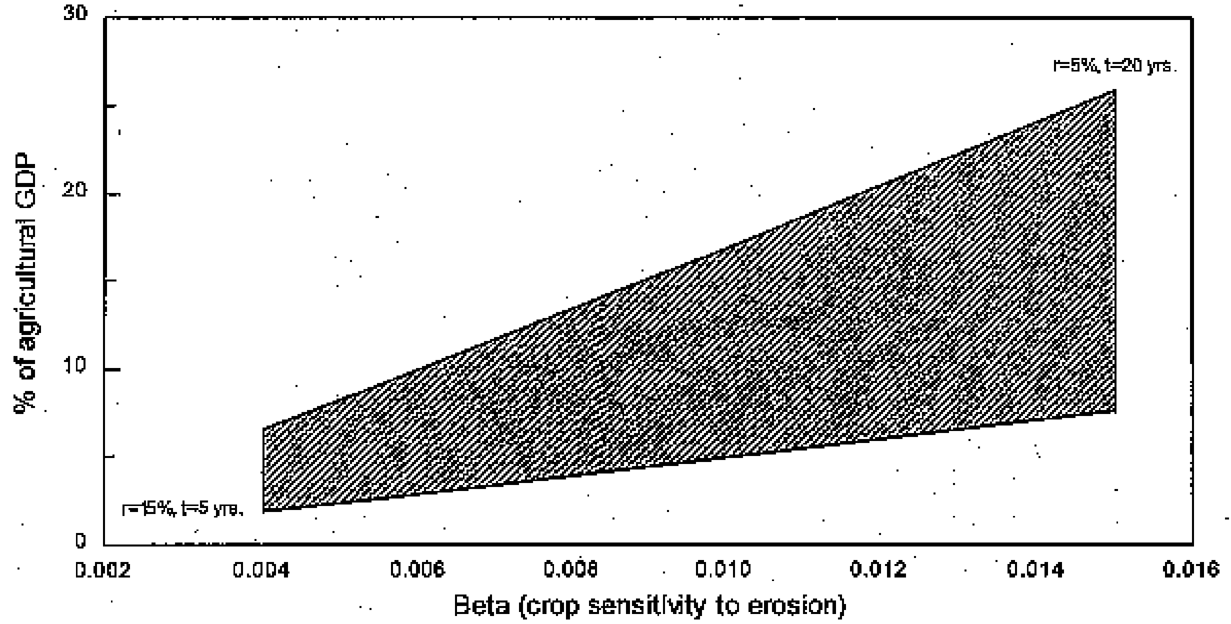
Given two points: [Q=103,465 ha for P=40,000 CFA] and [Q=9,817 ha for P=65,000 CFA], and converting CFA values into US$ equivalents, we then solve for $A$ and $\alpha$.

welfare loss is about US$1.1 million, or less than one tenth of one percent of GDP. In other words, the loss of economic welfare due to the impact of soil erosion on future farm income is only significant if we assume the lowest possible cost of soil conservation. Increasing the severity of the erosion-yield relation (Beta) raises the magnitude of total welfare losses, as would a decrease in the discount rate or a longer time horizon.

## 4.9 Sensitivity Analysis

The figures above rely on a number of assumptions that are not easily verified. Predicted soil losses are an obvious instance, and the most fundamental. Verifying the estimates of erosion would require years of painstaking measurement in the field. Other components of the model are also susceptible to criticism, but their influence is more readily checked. Figure 4.9 presents estimated total farm income foregone nation-wide as a percent of agricultural GDP, for a range of discount rates and time horizons, and for various assumptions about the severity of erosion's impact on crop yields (Beta).[31] These assumptions appear to have the greatest effect on the magnitude of estimated losses. With a short time horizon and a high discount rate, income foregone due to soil erosion is small (2 to 8%) relative to current agricultural income. Taking a longer view, erosion losses seem far more significant. Additional factors that affect the magnitude of estimated losses include the length of slopes on farm land, the ratio of cultivated to fallow land, and the change in variable costs resulting from a change in yield. The latter parameters are not tested here.

**Figure 4.9 Sensitivity Analysis**
Nationwide losses as a % of 1988 Mali Agricultural GDP



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[31] Based on total income foregone rather than welfare losses, due to the uncertainty of the latter.

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# 5 THE ON-SITE COST OF SOIL EROSION IN MALAWI

## 5.1 Introduction

This chapter describes a study of the economic cost of soil degradation on farm land in Malawi, using soil erosion as a proxy for overall fertility decline. Section 5.2 reviews the reasons why smallholder farmers in Malawi may not manage soil resources efficiently, in economic terms. Section 5.3 defines the scope of the analysis and the valuation method employed. Section 5.4 reviews the existing empirical data on soil degradation in Malawi and describes a simple model used to estimate soil erosion, in physical terms, based on a previous study of erosion hazard. The model is used, in combination with published data on land use, to estimate average rates of soil erosion for different areas. Section 5.5 goes on to link estimated soil losses to crop yields, using the same statistical relations that were employed for the Mali study (Lal 1987). Yield losses are expressed in terms of foregone farm income, using national crop budgets and data on cropping patterns in different regions, to determine on-site economic losses from land degradation at both a farm level and for the nation as a whole. Finally, in Section 5.6, sensitivity analysis is conducted on key variables.

## 5.2 Market Failures in the Agricultural Sector

Agriculture in Malawi accounts for about one third of national income, and about 80% of total employment (CEM/II, 1989). Most production is by smallholder farmers, cultivating small scattered plots by hand with minimal use of fertilizers. The major crop is maize, accounting for about 70% of the total cultivated surface area nationwide. No more than one third of households use chemical fertilizers on their crops. Under these conditions careful land husbandry is essential; the alternative is steadily declining yields and reduced rural incomes.

As in Mali, however, few farmers undertake soil conservation measures and, as before, the principal cause is poverty (GDP per capita was just $200 in 1990). A majority of the rural population lives at the margin of subsistence and can hardly afford to undertake such measures, even where they are aware of them. Moreover, with few assets and little or no "social safety net," most households are extremely vulnerable to even slight shortfalls in income. Such desperate circumstances are often associated with risk-averse behaviour and high rates of time preference, i.e. a tendency to discount long-term costs and benefits heavily, especially where major changes are involved (Barbier and Burgess 1992).

On the other hand, unlike Mali, customary land tenure systems do not appear to be a significant constraint on the adoption of soil conservation measures by smallholder farmers. Studies in Malawi suggest that households allocated farm land under customary tenure are generally assured of permanent access to it. Lack of legal title does not prevent farmers from making improvements, including afforestation and soil conservation works. On the contrary, studies of the Lilongwe Land Development Project suggest that the registration and titling of smallholder plots has little impact on land husbandry practices (Mkandawire 1984, Pervis 1984). Moreover, registration has not significantly improved farmers' access to commercial credit for purchase of agricultural inputs or capital investment.

A problem of tenure security does arise, however, where there has been significant expansion of the estate sector. In some areas, smallholders have been displaced to make room for new estates (Mkandawire and Phiri 1987). Where there is also high turnover of tenant farmers (as on many tobacco estates), there may be reduced incentives for implementation of soil conservation measures. A more widespread problem created by estate expansion has been the contraction of uncultivated land available to smallholders. This has hastened the opening of marginal land for farming (especially on steep slopes), as well as the shift to continuous cultivation and the exhaustion of soil fertility.

In summary, widespread rural poverty and poorly developed rural capital markets, combined with tenure insecurity in some areas, implies a general tendency for smallholders to discount future costs and benefits at a relatively high rate. This in turn will tend to discourage farmers from investing in soil conservation measures except in areas that are highly vulnerable to erosion, where the payback is large and immediate.[32]

## 5.3 Scope of the Analysis and Valuation Method

Recall that soil erosion can impose economic costs in two ways: through on-site reductions in crop productivity and farm income, and through off-site effects resulting from increased runoff, siltation, and water flow irregularities. The latter may affect the quality and reliability of urban water supply, the life span of hydro-electric power facilities, dredging costs for irrigation schemes, and fisheries productivity.

Data to estimate the off-site costs of erosion in Malawi are unavailable, but a number of factors suggest that these costs may be low. Ground water is plentiful in most areas, while filtering costs are a very small fraction of water supply costs. Malawi also has little hydro-electric and irrigation infrastructure. Fisheries may be more seriously affected, but the data needed to determine costs imposed by eroded sediments are not available. On the other hand, the size of the agricultural sector, combined with apparent market failures which lead farmers to deplete top soil at an inefficient rate (Section 5.2), suggest that on-site costs may be high.

The on-site costs of soil erosion may be evaluated in a number of ways: in terms of reduced crop yields, the replacement cost of eroded plant nutrients, or most directly in terms of the reduced resale or rental values of agricultural land. Evaluation of the replacement cost of eroded nutrients is an approach that has been applied in the neighboring country of Zimbabwe (Stocking, 1986). The method is based on a set of statistical relations linking soil loss to nutrient losses, derived from multi-year data from across Zimbabwe. Financial analysis

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[32] A minority of farmers in Malawi undertake soil conservation measures. Some are relatively well-off, large-scale farmers in the "estate" sector who invest in elaborate and expensive soil conservation measures, such as graded terracing. Others, including some of the very poorest farmers cultivating steep, rocky slopes with thin and highly erodible soils, undertake far simpler, labor-intensive measures such as piling up rocks extracted from their fields in lines running perpendicular to the slope of the land. The latter measures are typically not very effective but farmers working these marginal lands often cannot afford any better for lack of access to credit and/or labour. That they do anything at all is testament to the impact of erosion on productivity.

estimated annual losses of Nitrogen and Phosphorus worth US$150 million on arable land alone (30,000 $km^2$). As pointed out in the report, these losses understate the true cost of erosion, as they do not account for losses of soil organic matter, which can affect soil structure, water-holding capacity and nutrient availability.[33]

Evaluation of yield losses has the benefit of capturing all of the on-site effects of soil erosion on soil fertility and thus on farm productivity. Yields reflect not only the presence of major nutrients, but many other attributes of soil fertility. The problem is to find a link between soil degradation and crop yields. The first step is to quantify, in physical terms, the rate of soil degradation on farm land.

## 5.4 Land Degradation and Soil Erosion in Malawi

### 5.4.1 Existing field data

Data from field studies of fertility decline and soil loss in Malawi are scanty. From the farmer's perspective, the most relevant measure of land degradation is yield decline. Results of continuous maize trials at Chitedze Research Station, from 1955 to 1963 and for six different treatments of crop residues, reveal a mean decline of 49% over eight years for unfertilized maize, or a 9.1% average annual decline during the period (Dept. of Agr. Annual Report for *1962/63*, pub. *1965*). A more recent depiction of yield decline for unfertilized local maize compares average yields for four ADD's in 1957-62 versus 1985-87, revealing a mean total decline of 41% over the period, or an average annual decline of about 2% (Twyford, 1988).

Another measure of fertility decline is a decrease in organic matter and plant nutrients under cultivation. Analysis of soil sample data from fertilizer trials carried out at Bvumbwe Agricultural Research Station, on land continuously cropped with tea over 25 years and with minimal application of fertilizer (45 kg N $ha^{-1}$ $yr^{-1}$), revealed a 41% total decline in organic matter, a 38% decline in total Nitrogen, and a 5% decline in total Phosphorus, relative to uncultivated land (Maida and Chilima, 1981).

The measure of land degradation employed in this analysis is physical soil loss, in tons per hectare. The justification for this simplification comes from studies showing that soil loss is a reliable predictor of changes in soil nutrient content, soil pH, and moisture retention (Lal 1981). A few field studies have measured soil erosion under various crop cover and land husbandry regimes in Malawi (Table 5.1). Reported soil losses are not strictly comparable, due to widely varying plot sizes (from 1 - 170,000 $m^2$). On the average, however, annual soil loss under traditional cultivation (ie. maize, weeded and ridged) is about 19 t/ha. Average annual rainfall recorded at the five stations was 950 mm, and the mean slope was 14%.

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[33] The replacement cost approach is not used here, although data from the Soil Erosion Research Project at Bvumbwe would permit an estimation of the relation between soil loss and nutrient loss under conditions in Malawi (Amphlett, 1986).

**Table 5.1 Field measurements of soil erosion in Malawi**

| Station | Source | Slope (%) | Mean Rainfall (mm/yr) | Plot Size (ha) | Crop Cover & Husbandry | Mean Soil Loss (t/ha/yr) |
|---|---|---|---|---|---|---|
| Bvumbwe | Amphlett 86 | 7.2 | 987 | 7.8 | physcial structures & full land use plan | 0.1 |
| Mindawo | " | 8.8 | 964 | 5.3 | traditional cultivation | 10.6 |
| Mindawo II | " | 8.1 | 1032 | 6.7 | physical structures & traditional cultivation | 2.9 |
| Mphezo | " | 7.1 | 1004 | 17.2 | eucalyptus plantation | 0.1 |
| Nkhande | Chome 89 | 44.0 | 1300 | 0.02 | ridged maize | 54.2 |
| " | " | " | " | " | ridged maize alley cropped with leucaena | 7.2 |
| M'mbelwa | Machira 84 | 6.0 | 824 | 0.005 | bare soil, unridged | 11.2 |
| " | " | " | " | " | Rhodes grass | 2.8 |
| " | " | " | " | " | maize, ridges along the slope | 7.9 |
| " | " | " | " | " | mazie, ridges across the slope | 1.2 |
| Zunde | Kasambara 84 | 3.0 | 770 | 0.005 | bare soil, unridged | 25.0 |
| " | " | " | " | " | Rhodes grass | 2.3 |
| " | " | " | " | " | maize, unridged | 24.5 |
| " | " | " | " | " | maize, ridged | 15.3 |
| Bunda | Weil 82 | 6.0 | 886 | 0.0001 | maize, weeded | 12.1 |
| " | " | " | " | " | maize, unweeded | 4.5 |

### 5.4.2 Predictive models of soil erosion

The leading predictive model for soil erosion research is the Universal Soil Loss Estimation (USLE) model, developed in the U.S.A. (Wischmeier and Smith, 1978). Although widely tested and corroborated, some authors dispute the validity of the USLE model under the conditions found in southern Africa (Stocking 1987).

An alternative model for this region is the Soil Loss Estimation Model for Southern Africa (SLEMSA), developed in Zimbabwe (Elwell, 1978; Elwell and Stocking 1982). SLEMSA was designed for use in countries with limited capacity to generate the physical data required by the USLE and other models. A preliminary evaluation of SLEMSA under Malawian conditions compared the predictions of the model to actual soil loss measured on experimental catchments near the Bvumbwe Agricultural Research Station (Mwendera 1988). The results were inconclusive, from a statistical standpoint, due to insufficient data.

A modified version of SLEMSA has been developed, again in Zimbabwe, for reconnaissance level evaluation of erosion hazard (Stocking, Chakela and Elwell 1988). The methodology is designed to assess the relative risk of erosion over large areas, expressed in Erosion Hazard Units (EHU). The model uses precipitation data to estimate rainfall energy (E), which is combined with an index of soil erodibility to calculate an erosion hazard index ($I_b$). The protection provided by vegetal cover is also incorporated, along with average slope (X). The authors stress that the model is not designed to predict soil losses in tons per hectare, since it fails to account for the deposition of eroded sediments within catchments. The technique was first applied in an Erosion Hazard Mapping of Zimbabwe (Madhiri and Manyanza, 1989).

### 5.4.3 Erosion hazard mapping of Malawi

An evaluation of erosion hazard in Malawi was carried out by two members of the Land Husbandry Branch of the Department of Agriculture (Khonje and Machira, 1987), using the methodology developed in Zimbabwe. The authors prepared a 10x10 km grid map of Malawi at 1:1,000,000 scale, which displays the mean erosion hazard (EHU) for 1,044 grid squares (Annex G). The results are also presented in tabular form in an appendix to their draft report, with rainfall energy (E), erosion hazard index ($I_b$), vegetal cover ratio (C), mean slope (X) and EHU listed for 1,048 grid squares.[34] EHU values range from 0 to a maximum of 7,195, with a mean value of 328 (weighted by the estimated proportion of each grid square falling inside the boundaries of Malawi). Mean slope on all areas is 6.3%.

In their report the authors present a simplified EHU map (scale 1:3,000,000), on which EHU scores have been grouped into eight categories. For each category they assign an expected value of annual soil loss, in tons per hectare (ignoring the explicit warning of the method's designers not to do so). The rule used for conversion is shown in Table 5.2.

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[34] The copy of the report used for this study was incomplete and lacked parts of the appendix. Moreover, 127 grid squares shown on the map and listed in the report are recorded as having different values. This analysis generally used values reported in the appendix, in preference to those on the map, except where the former are missing in the available copy. It was possible to reconstruct mean slope values for grid squares missing in the report appendix, by extrapolating from EHU values shown on the map.

**Table 5.2 Erosion Hazard and Expected Soil Loss**
(From Khonje and Machiru, 1987)

| Erosion Hazard (EHU) | Category | Soil Loss (tons/ha/yr) |
|---|---|---|
| 0 - 10 | 1 | 0 - 5 |
| 11 - 25 | 2 | 6 - 10 |
| 26 - 50 | 3 | 11 - 15 |
| 51 - 100 | 4 | 16 - 20 |
| 101 - 250 | 5 | 21 - 30 |
| 251 - 500 | 6 | 31 - 40 |
| 501 - 1000 | 7 | 41 - 50 |
| > 1000 | 8 | > 50 |

While recognizing the danger of exaggeration inherent in converting EHU into soil loss, the estimates of annual erosion made by Khonje and Machira are adopted here. It cannot be over emphasized, however, that *the analysis presented here is only an illustration of the possible extent, distribution, and costs of land degradation, rather than an exact representation.*

The conversion rule used by Khonje and Machira is a step function, and ignores intermediate values within categories. Their rule is easily transformed into a general equation for converting EHU into expected soil loss, using simple regression analysis. The best fit was established with a set of three equations:

For: $0 < EHU < 500$ . . . . . . . . . . $E = 1.968(EHU)^{0.486}$ (1)

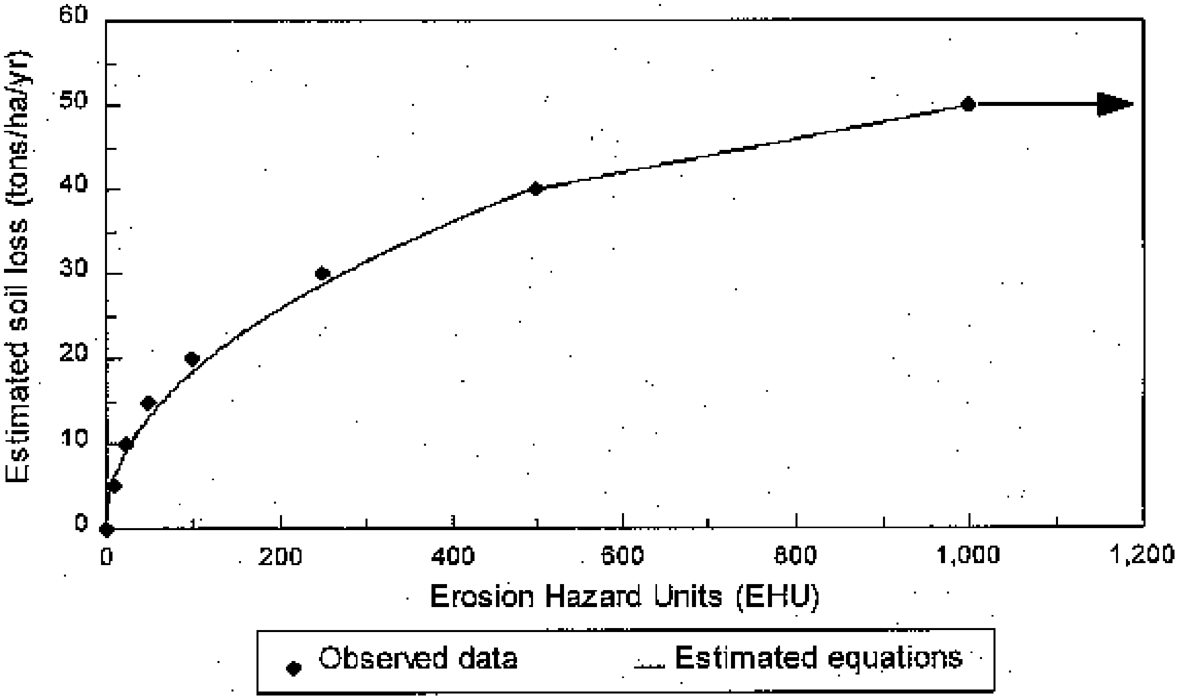
Adj. $R^2 = 0.976$
T-statistic = 15.7

$500 < EHU < 1000$ . . . . . . . . $E = 30 + 0.02(EHU)$ (2)

$1000 < EHU$ . . . . . . . . . . . . . $E = 50$ (3)

The estimated relationship is depicted in Figure 5.1. A maximum soil loss rate of 50 t/ha/yr was assumed for all grid squares with EHU greater than 1000.

**Figure 5.1 The Relation between Erosion Hazard and Soil Loss**
Malawi, Southern Africa (after Khonje and Machiru, 1987)



### 5.4.4 Land use data base

Information on land use in Malawi was derived from 1:1,000,000 scale maps provided by the Land Husbandry Branch, showing the limits of Districts, Rural Development Projects (RDP), Special Crop Authorities (SCA), National Parks, Forest and Game Reserves. By manually tracing and overlaying all of these maps with the erosion hazard map of Khonje and Machira, and estimating the proportion of each EHU grid square lying within a particular administrative unit, a data base of 1,855 land use units was compiled. The mean surface area of the map units is about 51 km². For each unit six attributes were recorded, of which the first three are taken directly from Khonje and Machira:

(i) grid coordinates,
(ii) EHU score,
(iii) mean slope (0.8%, 2.6%, 5.2%, 9.0%, or 13.5%),
(iv) estimated proportion of grid square falling within the boundaries of Malawi,
(v) estimated proportion falling within a specific administrative area,
(vi) the name of the specific administrative area.

The last of these attributes assigns to each map unit one of 155 labels, corresponding to the RDP, district, special crop authority, game or forest reserve in which it lies. The data base thus generated is by no means a definitive analysis of land use in Malawi. However, the estimates of the surface area of major land use categories used here correspond closely to previously published figures (see Annex H).

The land use data base permits the distinction of reserved areas, which are excluded from analysis of the costs of soil erosion, on the assumption that most if not all of this land is uncultivated. It is also assumed that some unreserved swampy land is either not cultivated or receives significant deposits of eroded sediment (i.e. no net soil loss). Finally, the very steepest slopes are assumed to be uncultivated.

Three sources give estimates of the total area of "uncultivable" swamps and steep slopes in Malawi (Table 5.3). These figures were used to specify rules for excluding certain grid squares: uncultivated swampy land was defined as all grid squares with mean slope equal to 0.8% and EHU scores below 8. Uncultivated steep slopes were defined as all squares with mean slope equal to 13.5% (the highest range). The latter rule results in an excluded area somewhat smaller than other estimates of land with slopes over 12%, which are considered unarable by the Land Husbandry Branch, but are in fact often cultivated.

**Table 5.3 Uncultivable land in Malawi (km$^2$)**

| Source | Dambos, swamps and floodplains | Steep slopes |
|---|---|---|
| National Physical Development Plan (1986) | 6,190 a/ | 23,666 b/ |
| Brunt, Mitchell and Zimmerman (FAO 1984) | 8,800 a/ | 20,500 b/ |
| Stobbs and Jeffers (1985) | 6,935 c/ | 7,155 d/ |
| Present analysis | 5,964 e/ | 16,720 f/ |

Notes: a/ Unreserved, uncultivated
b/ Unreserved, slope > 12%
c/ Uncultivated swamp, marsh, dambo; water surface
d/ Uncultivable steep & rugged country, slope > 15°
e/ Grid squares with mean slope = 0.8% and EHU < 8
f/ Grid squares with mean slope = 13.5%

With these rules of exclusion and the data base described above, the total surface of each administrative area is calculated, distinguishing uncultivated reserves, swampy land and steep slopes. Gross arable land is what remains and is the area assumed subject to crop losses arising from erosion. These estimates may be compared to previously published figures on land use in Malawi, which vary widely (Table 5.4). A full tabulation of land use estimates generated in this study and a comparison to other estimates, by RDP and by District, is provided in Annex H.

Table 5.4 Land use in Malawi (km²)

| Land Use | Present Analysis | Mkandawire & Phiri 1987 | NRDP[1] 1989 | Brunt et al. 1984 | NPDP[2] 1986 | Stobbs & Jeffers 1985 |
|---|---|---|---|---|---|---|
| Total Area[3] | 94,407 | 94,270 | 94,275 | 94,400 | 94,274 | 94,465 |
| Exclusions: | | | | | | |
| Parks & Game Reserves | 10,729 | 10,000 | 10,913 | 11,800 | 10,913 | N/A |
| Forest Reserves | 10,850 | 9,870 | 8,660 | 7,300 | 7,238 | N/A |
| Dambo, swamp, steep slopes | 22,684 | 23,670 | 29,865 | 29,300 | 29,856 | 14,090 |
| Gross Arable[4] | 50,146 | 40,650 | 43,395 | 43,000 | 51,856 | 80,375 |

Notes:
1. Malawi National Rural Development Program, World Bank report No. 7539-MAI, 1989.
2. National Physical Development Plan, 1986.
3. Excluding lakes Malawi, Malombe, Chiuta, Chilwa, Chikukutu
4. Gross arable surface may be less than total area minus reported exclusions, due to some studies' consideration of settlements and infrastructure, rock outcrops, surface water.

### 5.4.5 Estimated soil loss

Finally, for each map unit not excluded, the mean annual rate of soil erosion (in tons per hectare) is estimated using the equations derived from Khonje and Machira (1987). Summing across map units, it is simple to calculate the mean rate of soil loss by RDP and by District on gross arable land (weighted by the surface area of each affected map unit). Detailed results are presented in Annex I.

For Malawi as a whole, the estimated mean current rate of soil erosion is 20 t/ha/yr on gross arable land. Recalling that the approach used here assumes a maximum rate of 50 t/ha/yr on any map unit, the highest estimates of erosion on arable land occur in Nkhata Bay District (43 t/ha), Chiradzulu District (39 t/ha), and Dowa Hills RDP (36 t/ha). The minimum estimate (10 t/ha) occurs in Balaka and Kawinga RDP's.

## 5.5 The Economic Impact of Soil Erosion

### 5.5.1 From soil loss to crop yields

There are very few data linking crop yields to soil erosion in Malawi. Experiments at Nkhande Research Station on a 44% slope show yields under traditional cultivation falling 62% between 1985/86 and 1986/87, from 815 to 308 kg/ha, where annual soil loss was 76 t/ha. On an adjoining alley-cropped plot, soil loss averaged only 3.7 t/ha/yr, and yields rose over the same period from 2,050 to 2,700 kg/ha (Chome, 1989). While the example is illustrative of the effects of soil loss (and the potential benefits of alley-cropping), it cannot provide a general rule for estimating yield losses arising from erosion.

This analysis therefore adopts the same model used in the Mali study to predict crop yield losses from estimated rates of erosion. Recall that the model is a generalized version of statistical relations between crop yields and soil loss, which were estimated using data from side-by-side, multi-year trials carried out in Nigeria at the International Institute for Tropical Agriculture (Lal, 1987). Agricultural conditions in Malawi and southwestern Nigeria are of course not comparable, but the general form of the crop response to soil erosion is assumed to be similar. As in the Mali study, the equation is used to calculate a percentage yield decline for every level of soil erosion, using a range of coefficients ($\beta$) to estimate a wide range of potential yield losses.

The generalized IITA equation is applied to every map unit in the data base, excluding reserved and unarable land. Results by RDP and by District are presented in Annex J. For Malawi as a whole, estimated mean annual yield losses lie between 8% and 25%, for $\beta$ equals 0.004 and 0.015 respectively. Maximum yield loss lies between 18% and 53%, for soil loss of 50 t/ha/yr.

### 5.5.2 Crop budgets

Crop budgets provided by the Planning Division of the Ministry of Agriculture (MOA) are used to value yield losses arising from soil erosion. Farmers are assumed to reduce the use of variable inputs in the same proportion as gross revenues decline. Applying the estimated percentage yield loss directly to gross crop margins gives an estimate of the gross value of losses arising from erosion.

Gross margins are defined as total revenue per hectare (mean yield multiplied by official ADMARC prices), less the total cost per hectare of using all *recommended* inputs (seed, fertilizer, and pesticides), but not including labour inputs. In other words, intermediate inputs are excluded, leaving value added. Labour is assumed to be a fixed cost of production. An alternative financial analysis from the farmer's point of view applies estimated percentage yield losses to *net* farm income, on the assumption that labour is not fixed.

Gross margins for twelve crops or crop mixtures are taken from current MOA data tables, using values for 1989/90. Where values are not available for specific crops, figures are taken from Agro-economic Survey (AES) Report No. 55 (1987). AES gross margins are inflated from 1984/85 to 1989/90, using the growth rate of gross margins for the same or similar crops, as reported in the MOA data tables. AES data also includes net farm income, which is similarly inflated to 1989/90. Both gross margins and net income as used in the study are reported in Annex J.

### 5.5.3 Cropping pattern

Estimates of the total surface area cultivated each year vary widely among different sources. The baseline figures used are from the *1987/88 3rd Crop Estimate*, prepared by the Planning Division (MOA). These give the total cultivated surface area, by crop and by Agricultural Development Division (ADD). According to this source, the total cultivated area of Malawi in the 1987/88 crop year was 18,218 km$^2$.

Data on cropping patterns in each ADD are taken from the Annual Survey of Agriculture (ASA) for 1980/81 to 1985/86, as reported by the World Bank (NRDP, 1989), combined with data from the 1987/88 ASA and the AES Report No. 55. Unfertilized 'local' (indigenous) maize accounts for about 37% of the total cultivated surface area of Malawi, while all maize varieties taken together account for 69% of the cultivated surface. Major cash crops, including cotton, tobacco, coffee and tea only account for about 5% of total cultivated area. Detail for each of sixteen crops, by ADD, is presented in Annex J.

By combining information on gross margins and cropping patterns it is easy to estimate the mean contribution of each crop to average gross margins per hectare on cultivated land.[35] Summing the contributions of each crop in each ADD yields composite gross margins for all crops taken together, in Kwacha per hectare. For Malawi as a whole, composite gross margins are estimated at 249 K/ha in 1989/90 (weighted by the baseline estimate of cultivated surface in each ADD).[36] Again maize accounts for about 70% of this figure. The highest value is in Lilongwe ADD (302 K/ha), while the lowest is in Karonga ADD (161 K/ha). Detailed results by crop and by ADD are presented in Annex J.

### 5.5.4 Economic losses: baseline results

Finally the estimated percentage yield losses, for various values of $\beta$, are applied to composite gross margins. The result is an estimate of average annual losses due to erosion, in Kwacha per hectare.[37] For Malawi as a whole, estimated annual losses are in the range of 20 - 64 K/ha (for $\beta = 0.004$ and 0.015, respectively), or between 8% and 26% of composite gross margins, excluding rice and root crops. The greatest losses occur in Lilongwe ADD (25 - 81 K/ha, for $\beta = 0.004$ and 0.015), due to the relatively high gross margins obtained there.

Multiplying mean annual losses per hectare by baseline estimates of cultivated area yields an estimate of total losses by ADD, for various values of $\beta$. Summing across ADD's gives an estimate of the annual loss of national agricultural income arising from soil erosion. For $\beta = 0.004$ and 0.015, these calculations yield roughly 36 and 116 million Kwacha, respectively (equivalent to US$13 and $42 million). To put these numbers in perspective, they correspond to 2.4% and 7.7% of Malawi's gross agricultural product (GDP) in 1990. Detailed results are presented in Table 5.5 and in more detail in Annex K.

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[35] Rice is excluded from the analysis, on the assumption that it is grown on relatively flat lowland soils, which are not subject to serious soil erosion. Root crops are also excluded, despite their importance in cropping systems, for lack of budgetary data.

[36] Multiplying composite gross margins by the baseline cultivated surface area yields a value of 453 million Kwacha, which may be considered a rough estimate of the contribution of these crops to total 1990 agricultural GDP (1.510 billion K).

[37] In contrast to the Mali study, baseline erosion losses are expressed here as a one-time cost rather than as the discounted present value of a series of losses over a defined period of time. See Section 5.5.3 (and Annex K) for an estimate of the capitalized value of recurrent losses.

**Table 5.5 Estimated annual gross margin losses by ADD**
(1989/90 prices, US$1 = 2.75 Malawi Kwacha)

| | KRADD | MZADD | KADD | LADD | SLADD | LWADD | BLADD | NADD |
|---|---|---|---|---|---|---|---|---|
| Gross Margin (K/ha) | 161 | 231 | 296 | 302 | 227 | 221 | 200 | 191 |
| Mean loss (K/ha/yr) | | | | | | | | |
| Beta = 0.004 | 17 | 19 | 22 | 25 | 14 | 11 | 22 | 12 |
| Beta = 0.015 | 55 | 63 | 74 | 81 | 46 | 38 | 68 | 40 |
| Cultivated area (km$^2$) | 663 | 1,417 | 2,615 | 5,215 | 1,046 | 3,057 | 3,187 | 1,018 |
| Total loss (K million) | | | | | | | | |
| Beta = 0.004 | 1.1 | 2.7 | 5.9 | 13.0 | 1.4 | 3.4 | 6.9 | 1.2 |
| Beta = 0.015 | 3.6 | 8.9 | 19.3 | 42.4 | 4.8 | 11.6 | 21.5 | 4.1 |
| Percent of total | 3.2% | 7.7% | 16.4% | 36.4% | 3.9% | 9.4% | 19.5% | 3.4% |

## 5.6 Sensitivity Analysis

### 5.6.1 Higher estimates of cropped area

Some assessments of total cultivated area by ADD are considerably higher than the baseline 3rd crop estimates obtained from the Ministry of Agriculture. Land use data from Mzuzu, Kasungu, Lilongwe, Blantyre and Ngabu ADD's suggest cultivated surface areas up to twice those reported in baseline estimates. Using these higher values where available results in a total cultivated surface area of at least 25,556 km$^2$. Aggregate income losses are correspondingly higher, ranging between 3.4% and 10.9% of 1990 agricultural GDP. Detailed results by ADD and for different values of $\beta$ are contained in Annex K.

### 5.6.2 Financial analysis

Farmers will tend to define erosion losses more narrowly, in terms of reduced *net* revenues (i.e. farm income net of all inputs including labour). Data on net revenues for various crops is provided by AES Report No. 55 (1987). Assume that farmers will adjust labour and other inputs in the same degree as yields decline and then apply percentage yield losses directly to composite net revenues, which are calculated in the same manner as composite gross margins. The resulting estimates of annual financial losses range from 10 to 33 K/ha, for Malawi as a whole, or between 8% and 26% of composite net farm income.

### 5.6.3 Recurrent losses

Soil erosion in one year has an effect on yields in future years as well, as soil fertility declines absolutely. As in the Mali study, the present value of recurring losses is calculated by summing the discounted value of future losses over a defined time horizon.[35] A benchmark discount rate of 10% and a ten year planning horizon are used here, for comparison with the Mali study.

When the impact of current erosion on future yields is accounted for, the range of estimated field level and aggregate losses for Malawi as a whole rise dramatically. Using composite gross margins, the resulting estimates of field level losses range between 140 and 456 K/ha for every year of soil loss, or between 56% and 183% of composite (annual) gross margins ($\beta = 0.004$ to 0.015). Estimated aggregate losses based on these figures are equivalent to 17% and 55% of 1990 agricultural GDP. Figure 5.2 presents results in terms of agricultural GDP, for a range of discount rates and time horizons.

Note that famers' private rates of time preference will tend to be higher, on average, than for society as a whole. Evidence from studies of the informal credit sector in Malawi suggest private rates of interest as high as 50 to 100% per year (Malawi Draft Financial Sector Study, World Bank, 1990). While interest rates are not necessarily an accurate reflection of time preference, it is clear that as the discount rate becomes large, future losses appear less important. In other words, smallholder farmers will tend to ignore all but *current* yield losses arising from soil erosion.

### 5.6.4 Other areas of uncertainty

Yield estimates used by the Ministry of Agriculture in the calculation of gross margins and net revenues may be considered somewhat higher than typical yields achieved on smallholder farms in Malawi. On the other hand, the prices of agricultural commodities in rural markets are typically somewhat higher than the official ADMARC prices used here. Lack of reliable alternative crop price and yield data prevented the construction of more "realistic" crop budgets but it is assumed that discrepancies in the official figures more or less cancel out.

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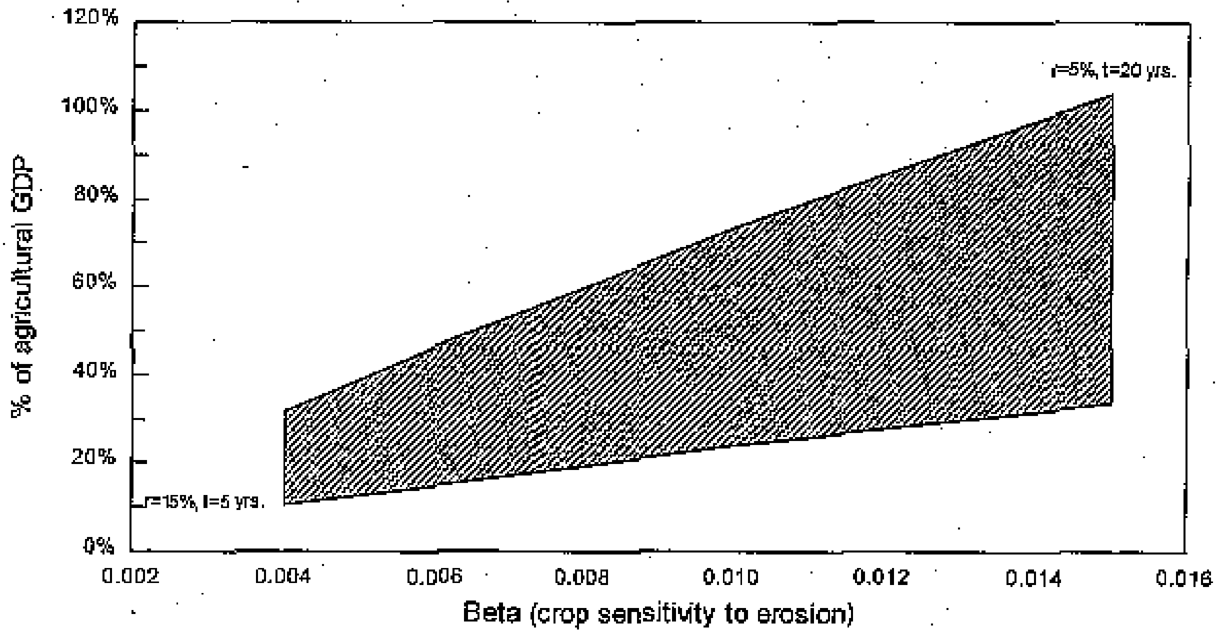
[35] For simplification it is assumed that the nominal loss in the baseline year is repeated in subsequent years. The present value of current and discounted future losses arising from one year of average soil loss is then calculated as the sum of a geometric series, which simplifies as:

$$L_c = L_0\left(\frac{a^{n+1}-1}{a-1}\right)$$

where: $L_c$ = NPV current and future losses
$L_0$ = current one-year loss
a = 1/1+r
n = time horizon (years)
r = discount rate

Another information gap is the cost and the approximate extent of adoption of soil conservation measures by farmers. If such data were available, it would have been possible to estimate net welfare losses due to soil erosion in Malawi, as was done for Mali.[39]

**Figure 5.2 Sensitivity Analysis**
Capitalized nationwide losses as a % of 1990 Malawi agricultural GDP



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[39] A recent independent study compared the estimated loss of farm income, as reported above, with the costs and potential yield benefits (due to reduced erosion) of a no-till cropping system (Eaton 1993). In most cases, the costs of the no-till system were found to exceed the incremental yield benefits both on an annual basis and in present value terms. Thus if viable alternatives do not exist, farmers can be expected to maintain their traditional cultivation practices, in spite of the apparent magnitude of erosion losses.

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## 6 CONCLUSION

Soil degradation occurs both naturally and as a consequence of economic activity. The costs of soil degradation include reduced productive potential and off-site impacts. Soil degradation in agriculture arises primarily from clearing and cultivation, resulting in accelerated erosion of fertile top soil under rainfall. The impact of soil degradation on agricultural productivity and on downstream water users can be measured and evaluated in economic terms, although relevant data are often difficult to obtain. There is an urgent need to reinforce efforts to collect baseline data on a regular and widespread basis, with an emphasis on measurement of soil degradation at a regional level. Efforts are also required to improve our understanding of the link between physical degradation, on-site productivity impacts and off-site effects.

Land husbandry strategies adopted by farmers may be described in terms of the private costs and benefits of soil conservation. The decision to conserve soil is a function of many variables, including the marginal product of fertile soil, agricultural input and output prices, risk and uncertainty, time preference and the opportunity cost of labour and capital, and information. More research is needed to improve our understanding of the perceptions and motivations of producers with regard to soil conservation, and how different factors affect their land use decisions.

Careful consideration of underlying social and economic conditions, policies and institutions can reveal when and why private soil conservation efforts may be inadequate, and the type of policy response required to modify private incentives. Quantitative analysis of the costs and benefits of soil conservation can indicate the magnitude of economic losses due to inefficient land use, and help to determine the appropriate scale of public intervention where necessary. If sufficient data are available, analysts may also attempt to determine the relative importance of different factors affecting land use decisions, and the potential impact of specific policy changes.

Analysis of the cost of soil erosion in both Mali and Malawi is based on the assumption that soil resources are being depleted by most farmers at an excessive and economically inefficient rate. The presumed cause of over-exploitation is the relatively high rate at which farmers discount future income and the failure to account for any off-site costs. Farmers' high rate of time preference is attributed to insecurity of land tenure, thin capital markets, and acute poverty in rural areas.

Economic losses due to soil erosion in both countries are probably high enough in certain areas to justify moderate investment in farm-level soil conservation, even under relatively conservative assumptions. In Mali, under more extreme assumptions about the impact of erosion on crop yields, and more favorable assumptions about the cost of soil conservation, most of the productive agricultural land (south of the capital, Bamako) may merit attention. This analysis does not appear to justify soil conservation efforts on farm land north of Bamako, although the additional benefits of water-harvesting in these areas may make profitable investments that are not justified on the basis of erosion alone. Total welfare losses arising from excessive soil erosion are significant only for low estimates of the cost of conservation. Given this caveat, the general implication for public policy is that government should undertake measures to relieve or counter the market failures which lead farmers to over-exploit soil resources.

Lack of data on the costs of soil conservation measures in Malawi prevents a similar analysis of priority areas for conservation. However, economic losses are generally higher in Malawi, as a percentage of farm income, reflecting higher rates of soil loss on hilly land. This suggests that the economic justification for soil conservation efforts is probably at least as strong as in Mali, if not more so. Table 6.1 compares and summarizes the results of the analyses of the on-site cost of soil erosion in Mali and Malawi.[40]

**Table 6.1 The On-Site Cost of Soil Erosion in Mali and Malawi: A Comparison of Results**

| | Mali | Malawi |
|---|---|---|
| Reference year | 1988 | 1990 |
| Per capita GDP (current US$) | $ 240 | $ 200 |
| Agricultural GDP (current $ millions) | $ 924 | $ 549 |
| Agr. GDP as % of national GDP | 45% | 30% |
| Cultivated area (km²) | 31,255 | 18,218 |
| | | |
| Farm gross margins (Value Added in US$/ha) | $ 165 | $ 90 |
| Farm net revenues (Profits per ha) | $ 33 | $ 46 |
| Mean soil loss (tonnes/ha/yr) | 6.5 | 20 |
| Maximum soil loss (tonnes/ha/yr) | 31 | 50 |
| Mean yield penalty ($\beta$ = .004 - .015) | 2 - 10% | 8 - 25% |
| | | |
| Current net revenue loss ($\beta$ = 0.004 - 0.015, per ha) | $ 2 - 6 | $ 5 - 15 |
| Capitalized net revenue loss (r=10%, t=10 yrs.) | $ 7 - 26 | $ 33 - 106 |
| Aggregate cap. loss (millions) | $ 31 - 123 | $ 59 - 195 |
| | | |
| Aggregate cap. loss (% of Agr. GDP) | 3 - 13% | 17 - 55% |
| Aggregate cap. loss (% of Nat'l GDP) | 1.5 - 6.0% | 5.0 - 16.4% |

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[40] Certain adjustments must be made to reconcile methodological discrepancies between the two studies. In particular, the Mali study considers net farm income forgone whereas the Malawi report focusses on 'gross margins.' The former considers labour a variable input and uses real prices, while the latter treats labour as a fixed input and thus charges yield penalties to it; the latter also uses official rather than market prices. Table 6.1 attempts to reconcile these differences, using a net revenue forgone approach (as in the Mali study). Both studies consider only currently cultivated land (no fallow). Values are based on exchange rates of 298 CFA/$ and 2.75 MK/$. Mali and Malawi GDP and Agricultural GDP are taken from the World Bank World Tables (1994). Note that farm gross margins for Mali include rice, while all other figures esclude it, as well as some other minor crops.

Analysis of the on-site costs of soil erosion in both Mali and Malawi appears to reinforce arguments for improving the security of rural land tenure among smallholder farmers. Economic theory suggests that permanent, tradeable property rights to farm land would help to reduce the rate at which farmers discount income foregone due to soil erosion and improve their access to formal credit. Recent experiments with large scale land titling of small holders in some East African countries, however, have had mixed results. Land tenure security may be less of a constraint on soil conservation than other factors.

A more promising area for intervention may be rural capital markets. Institutional credit is available in some areas at relatively low rates, but the supply is limited and generally restricted to the purchase of inputs for the production of export crops. Informal creditors do not impose such restrictions, but because of the scale of their operations they are generally obliged to charge very high rates of interest. This increases the effective cost of soil conservation, while decreasing the value of potential future benefits. Possible responses include direct provision of credit for conservation investment, relaxation of legal and other policy constraints on providers of informal credit, and promotion of risk-sharing links between informal providers of credit, such as rural credit unions and savings clubs. Finally, efforts to educate farmers about the costs and benefits of soil conservation techniques may also increase the likelihood of their adoption.

More detailed prescriptions for policy or programs would require a higher level of confidence about land degradation and its economic impact than these studies can provide. Better estimates of soil erosion must await an expanded physical data base, including multi-year field measurements of soil loss in various regions against which to calibrate synthetic predictions. Better economic data on farming systems would also improve the analysis, as would information on how farmers perceive and respond to reduced soil fertility.

The weakest link in this study is the relation between land degradation and agricultural productivity. A better understanding of this relation is critical to the evaluation of environmental problems in Africa and in the tropics generally. It is a topic especially deserving of additional research efforts.

# ANNEX A

## An Illustration of the Replacement Cost Approach:

## The Value of Soil Nutrients in Mali

We attempted an independent approach to the evaluation of soil erosion in monetary terms, inspired by a study carried out for Zimbabwe (Stocking 1986). This study related erosion to losses of three organic nutrients: nitrogen, phosphorus, and organic carbon. As we saw above, field experiments suggest that soil losses in tons per hectare are a relatively good proxy for losses of nutrients and other soil characteristics favorable to plant growth. Stocking sought to convert soil losses directly into nutrient losses, since the latter could be roughly valued in terms of commercial fertilizer equivalents. The resulting estimated losses for Zimbabwe are striking: 1.5 billion US dollars of losses per year, on all land; 150 million US dollars per year on arable land alone. This works out to about $50/ha/yr on communal farm land.

Our estimates for losses on Malian farm land, using a similar approach, are far more modest. They are comparable, however, to the losses estimated by way of yield effects, provided that we express both in the same terms. Recall our assumption above that the impact of erosion on yields would continue until fallowing. This led us to capitalize yield losses over many years. In contrast, we do not assume that eroded nutrients would have been available to plants more than once. Hence we do not capitalize nutrient losses. This procedural difference accounts for much of the divergence between losses estimated by way of crop yields, and losses derived from the nutrient approach.

### 1. From Soil Erosion to Nutrient Losses

Stocking's paper relates soil loss, in tons per hectare, to erosion of three organic nutrients: total organic carbon (O.C.), total nitrogen (N), and available phosphorus (P). The relation was established for each nutrient by way of bivariate regression equations, generated from data collected during soil erosion research in Zimbabwe over many years. The relation was found to be reliable ($R^2 > 90\%$), suggesting that soils are fairly uniform across Zimbabwe. The form of the equation is as follows:

$$Y = \beta * X^{\alpha}$$

where :

$Y$ = nutrient loss (kg/ha)
$\beta$ = coefficient varying by nutrient
$\alpha$ = " " "
$X$ = soil loss (kg/ha)

Given the distance between Mali and Zimbabwe, and the possibility that soils are not similar in the two countries, we chose to recalculate identical regression equations, using data from IITA in Nigeria (Lal 1976). As noted above, southwestern Nigeria is also far from Mali, but soil maps of West Africa suggest that the two countries share roughly comparable soils.

The IITA data include the weight of eroded sediments, and of eroded nutrients, under four soil management treatments, on four slopes, over four seasons. Due to the availability of records on losses of exchangeable potassium (K), in addition to the other nutrients measured by Stocking, we were able to add a fourth equation, reproduced with the others, below.

**The relation between soil erosion (tons/ha) & nutrient loss (kg/ha)**

(based on data from IITA, Ibadan, Nigeria)

Organic Carbon (Y) v. Soil Loss (X)

$\text{Ln } Y = 3.096 + 0.938 \text{ Ln } X$ Adj. $R^2 = 0.94$

$Y = 22.11 X^{0.938}$ 55 observations

Total Nitrogen (Y) v. Soil Loss (X)

$\text{Ln } Y = 1.04 + 0.872 \text{ Ln } X$ Adj. $R^2 = 0.97$

$Y = 2.83 X^{0.872}$ 36 obs.

Available Phosphorus (Y) v. Soil Loss (X)

$\text{Ln } Y = -3.15 + 1.052 \text{ Ln } X$ Adj. $R^2 = 0.87$

$Y = 0.043 X^{1.052}$ 55 obs.

Exchangeable Potassium (Y) v. Soil Loss (X)

$\text{Ln } Y = -1.36 + 0.879 \text{ Ln } X$ Adj. $R^2 = 0.96$

$Y = 0.257 X^{0.879}$ 55 obs.

These equations are readily compared to those used by Stocking by plotting points, for any level of soil loss (figures A.1-A.4). As may be seen from the graphs, regressions based on data from Nigeria predict slightly higher losses of organic carbon and total nitrogen than Stocking's equations, while predicted losses of phosphorus are considerably lower. Presumably this reflects differences in the nutrient content of soils from Ibadan, Nigeria, relative to the average for Zimbabwe.

**Figure A.1**

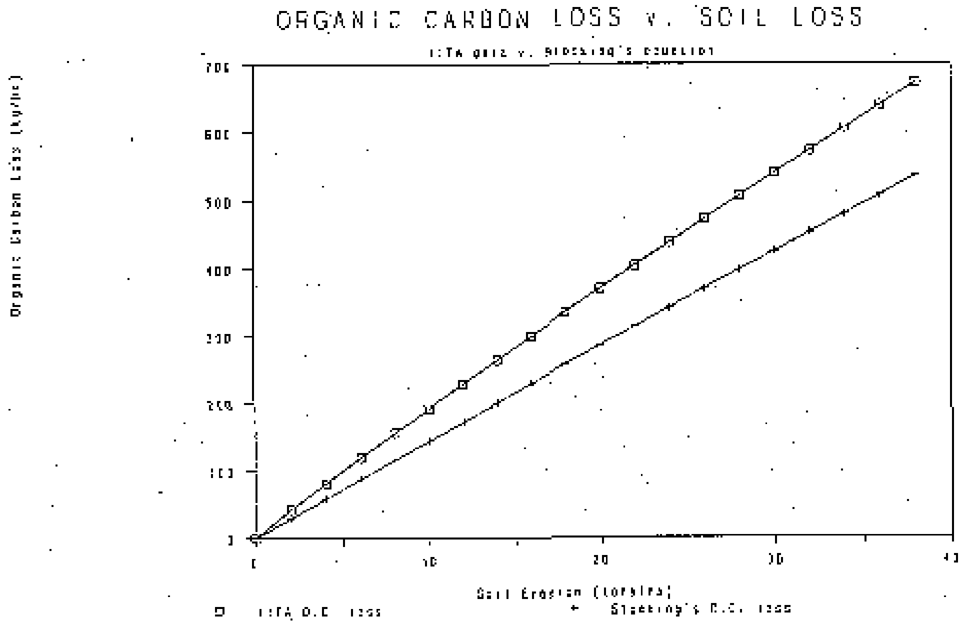
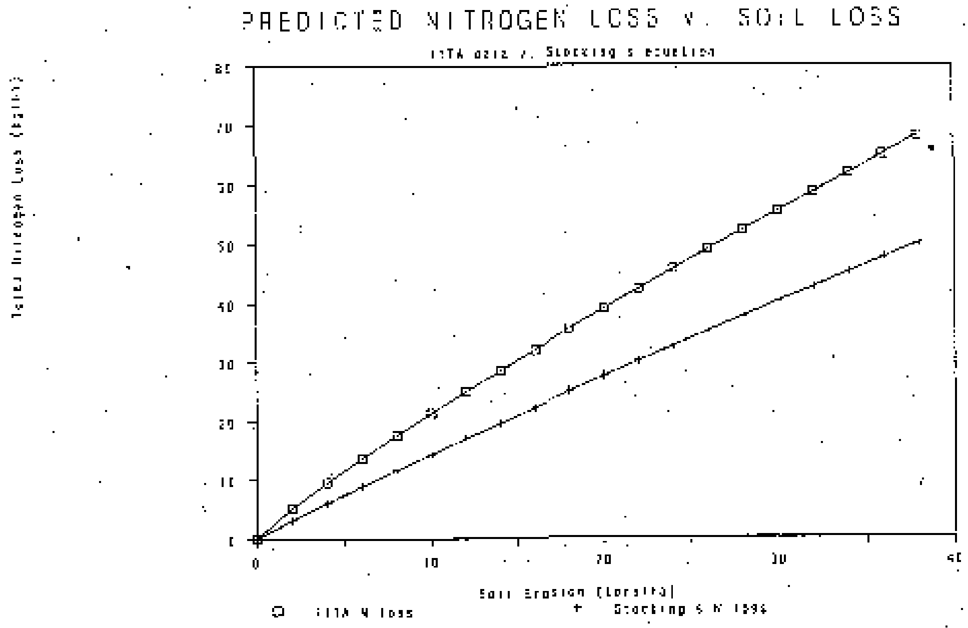
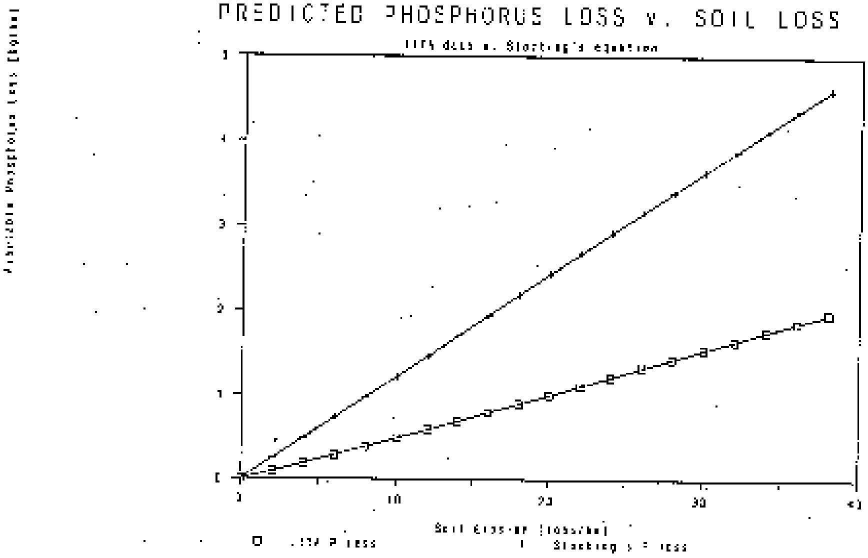


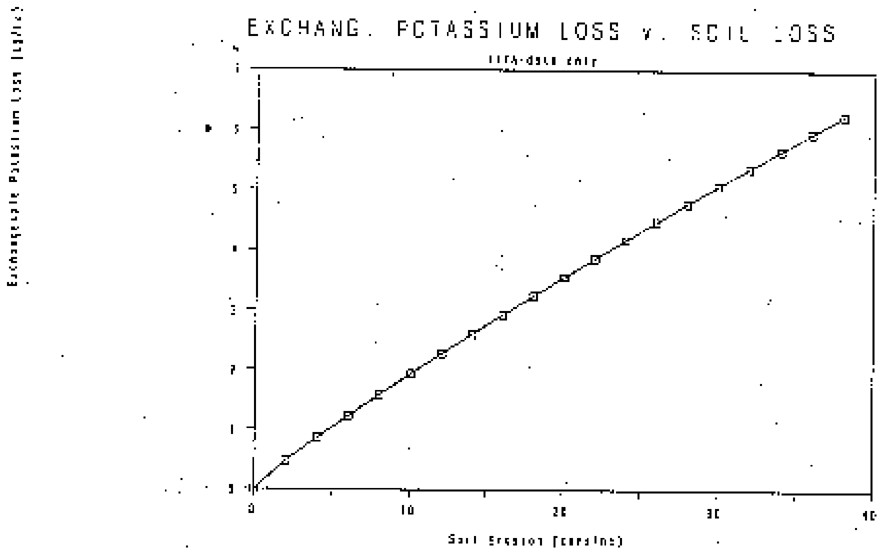
**Figure A.2**



### Figure A.3



### Figure A.4



The mechanics of estimating nutrient losses, and converting those losses into equivalent values of commercial fertilizers, are as follows:

i) estimate the mean rate (t/ha/yr) of soil loss for different types of crop land;

ii) estimate nutrient losses (kg/ha) associated with each rate of soil loss;

iii) estimate and price ($/ha) the fertilizer equivalents of those nutrients;

iv) estimate the total cultivated surface area (ha) subject to erosion;

v) calculate gross losses in national income (in dollars, and as % of GDP).

## 2. From Nutrient Losses to Fertilizer Equivalents

To translate kilograms/ha/yr of nutrient losses into equivalent weights and values of commercial fertilizer, we must make assumptions about the proportion of eroded nutrients that would have been available to plants, and the nutrient content of typical fertilizers. We then apply current prices (1988), including the cost of delivery to Mali. Nutrient contents and prices are from S. Carr (World Bank, pers. comm. 1989).

As may be seen by inspection of the equations used to estimate nutrient erosion, the total weight of losses is greatest for organic carbon. Following Stocking's example, however, we do not attempt to value O.C. losses in monetary terms. Organic carbon is assumed to be a vital but transient constituent of soil fertility (Lal 1987, Stocking 1986). The only comparable fertilizer would be manure, which decomposes so rapidly under tropical conditions that it may be misleading to ascribe a monetary value to it.

The second greatest losses, in terms of absolute mass, are of total nitrogen. For the base case, we assume that only 4% of total nitrogen would have been available to plants in any year (Stocking 1986, Nye & Greenland 1960).[1] We therefore discount the portion of eroded nitrogen that would have become available to plants in subsequent years. With a 10% discount rate, this has the effect of more than halving the present value of eroded nitrogen.

We then translate tons of "present" available nitrogen lost to erosion, for every map unit, into equivalent weights of Urea, with the assumption that every 100 kg of Urea contains 46 kg of available nitrogen. Finally, we apply a price of US $235/ton (1988), which includes an estimated $65/ton for freight and delivery to Mali.

Similar calculations are carried out for the much smaller estimated losses of phosphorus and potassium. In the first case, based on Stocking's example, we assume that all of the phosphorus lost ("Bray P") would have been available to plants in the same year. We make

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[1] Hobbs et al. (1980) suggest that mineralization of total nitrogen may be as high as 25% per year, in the tropics. In our calculations, using a 10% discount rate, this would increase the present value of available nitrogen losses from about 40% of total annual physical losses to about 87%.

the same assumption for exchangeable potassium. The respective conversion ratios and prices are: 23 kg P per 100 kg of Triple Superphosphate, at US $243/ton; and 46 kg K per 100 kg of Potassium Chloride, at US $168/ton.

The result of these calculations is the approximate cost of "replacing" the nutrients lost by way of soil erosion on crop land, in each of the TAMS map units. Since these losses vary directly with the rate of soil erosion, we did not generate a separate set of maps showing the value of nutrient losses. We can show, however, the average and maximum value of nutrient losses across the area analyzed, as in Table A.1. Note that the relative proportions of estimated monetary losses made up by N, P, and K are constant at about 77%, 10%, and 13%, respectively.

**Table A.1 Annual losses of N, P, & K on cropland**
(4% N avail./ yr., r = 10%, 1988 prices, US $1 = 298 CFA)

| Map sheet | Average loss | | Maximum loss | |
|---|---|---|---|---|
| | US $/ha | CFA/ha | US $/ha | CFA/ha |
| BOUGOUNI | 5.46 | 1,627 | 10.22 | 3,046 |
| BAMAKO | 2.32 | 5,331 | 22.32 | 6,651 |
| NARA | 0.79 | 235 | 2.01 | 599 |

The average nutrient loss, for the three map sheets studied as a whole, is estimated at US $3.07/ha/yr (CFA 915). To compare this to losses estimated by way of crop yields, however, we need to make another adjustment. We can reduce both approaches to a one year perspective, by considering only the nutrients that would have been available to plants in the current year, and only the effect of the current year's soil loss on current income.

On this basis, the two approaches yield comparable estimates of average losses over the three map sheets studied. Using the nutrient loss equations, and assuming that only 4% of total nitrogen would be available to plants in the current year (100% of P and K), average losses are about US $0.90 per hectare. If we assume that a higher proportion of total nitrogen becomes available to plants in any year, nutrient losses will be higher - $1.60/ha at a 25% mineralization rate. By comparison, using crop yields and farm budgets to determine average current losses, in 1988 prices (US $1 1983 = $1.15 1988), we derive values between $0.79/ha (Beta = 0.004) and $3.11/ha (Beta = 0.015).

In general, when the two approaches are compared over a common time horizon, the value of nutrient losses is lower than the value of yield losses. This may be attributed to the fact that nutrient losses capture only a small part of the total impact of soil erosion. They do not reflect, for example, the deterioration of water holding capacity or soil structure, or the development of surface crusts which impede the infiltration of runoff.

**Table A.2 Estimated annual nation-wide nutrient losses**
(r = 10%, Avail. N = 4%, est. 1988 prices, US $1 = 298 CFA)

| Map Sheet | Map Sheet Loss (CFA millions) | Surface Area (Multiplier) | National Loss (CFA millions) |
|---|---|---|---|
| Bougouni (South) | 392 | 1.25 | 490 |
| Bougouni (North) | 236 | 1.25 | 295 |
| Bamako (South) | 223 | 2.83 | 631 |
| Bamako (North) | 172 | 3.48 | 599 |
| Nara (South) | 32 | 3.50 | 112 |
| Nara (North) | 20 | 4.35 | 87 |

| | US Dollars (Millions) | Francs CFA (Millions) | % Mali GDP* | % Agric. GDP** |
|---|---|---|---|---|
| Nationwide annual nutrient losses on farm land | 7.41 | 2,214 | 0.36 | 0.80 |

Notes: * 1988 = 615.8 Billion CFA
** 1988 = 275.3 Biillion CFA (farming, forestry, fishing and livestock)

Table A.2 (above) presents estimated annual gross national nutrient losses. Table A.3, below, presents a range of gross national nutrient losses from annual soil loss, under different assumptions. We vary the proportion of total nitrogen that is mineralized, i.e., available to plants in the current year, as well as the discount rate applied to the eroded nitrogen that would have been mineralized in subsequent years.

**Table A.3 Sensitivity analysis: nation-wide nutrient losses**
(% of 1988 agricultural GDP)

| Discount rate | Proportion total Nitrogen mineralized | | |
|---|---|---|---|
| | 4% | 10% | 25% |
| 15% | 0.65 | 1.09 | 1.48 |
| 10% | 0.81 | 1.25 | 1.56 |
| 5% | 1.11 | 1.46 | 1.66 |

## References

Carr, S. 1989. Personal communication.

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Nye, P.H. and Greenland, D.J. 1960. *The Soil Under Shifting Cultivation*. Technical Communication No. 51. Commonwealth Bureau of Soils. Commonwealth Agricultural Bureaux. Farnham Royal, Bucks, England.

Stocking, M. 1986. *The Cost of Soil Erosion in Zimbabwe in Terms of the Loss of Three Major Nutrients*. Consultants' Working paper No. 3, Soil Conservation Programme, Land and Water Development Div., AGLS. FAO: Rome.

# ANNEX B

## The Universal Soil Loss Equation

## and Soil Deposition in Mali

The argument for modifying the USLE arises from the fact that the model ignores soil deposition and thus, when applied on a large geographic scale, it systematically overestimates soil loss (Stocking 1984). While USLE estimates of soil loss may be accurate for specific locations, other areas are gaining soil. Current estimates suggest that only 5 - 10% of eroded soil reaches the major rivers (Walling 1984). Thus 90 - 95% of the soil loss occurring on upland plots is redeposited somewhere down-slope, along the watershed.

But where is the soil redeposited? For this study, some light is shed by measurements carried out on vastly different scales for three separate studies of soil erosion in the neighboring country of Niger (mean annual rainfall = 400 mm). On a 0.34 ha plot at Allokoto, under traditional cultivation, measured soil losses from 1967-71 varied from 3.5 - 18.5 t/ha/yr (Delwaulle, 1973). On a cultivated watershed of 3.5 ha near Kountkouzout, with comparable slope and soil type, sediment load measurements from 1965-67 revealed soil losses of 12 - 13 t/ha/yr (Vuillaume, 1982). When sediment load measurements were made on the neighboring 117 km2 Ibohamane basin, from 1969-75, total soil loss was found to average 40 t/ha/yr (Heusch, 1980). 56% of the latter was found to result from erosion of gullies and stream banks, implying that sheet erosion averaged 17.6 t/ha/yr throughout the basin.

All of these measurements fall within the same order of magnitude, from plots of less than a hectare to over 100 square kilometers. When we move to the next level of study, however, soil loss falls dramatically. Sediment load measurements carried out on major rivers throughout West Africa reveal net soil loss on the order of 0.1 - 2 t/ha/yr (Table B.1). This implies that most eroded soil is deposited in large natural "sinks," or in man-made reservoirs.

If we assume that the measurements made in Niger are applicable to Mali, we might conclude that the USLE estimates of soil loss are accurate for all but the largest floodplains and depressions. In that case, little adjustment of the model would be required, except in a few strategic spots, such as the Inner Delta of the Niger.

For the present study, we simply set the soil erodibility parameter (K) equal to zero for all soil types subject to high rates of deposition, according to the soil/vegetation unit descriptions in volume II of the TAMS atlas (pp. B-41 to B-61). This accounts for 19 of the 68 soil-vegetation units defined in the Mali atlas and 12.7% of the total surface area (Table B.2). In fact, many of these units are receiving sediment from upstream or up-slope, of which only part is deposited and part passed on. Some may lose more soil than they receive, through gullying and scouring of stream beds. Without better data than are available, however, it is impossible to estimate the rate of deposition, let alone the effects of deposition on crop productivity.

## Table B.1 Sediment load for selected African watersheds

| Sediment load (t/ha/yr) | Country | River | Catchment (km2) | Source |
|---|---|---|---|---|
| 0.13-0.47 | Senegal<br>Mali<br>Gambia | Senegal<br>Niger<br>Gambia | ? | ORSTOM, personal communication |
| 0.331 | Senegal<br>Guinea<br>Niger<br>Mali<br>Nigeria | Niger | 1,114,000 | Milliman and Meade, 1983 |
| 0.85 | Cameroon | Mbam | 42,300 | Olivry, 1977 |
| 0.28 | " | Sanaga | 77,000 | " |
| 2.1 | " | Tsanaga | 1,535 | " |
| 1.55-4.38 | Nigeria | 4 rivers | Sokoto basin | Oyebande, 1981 |
| 2.19-7.39 | " | 5 rivers | Hadejiia-Jamaare basin | " |
| 0.2-0.8 | Nigeria | "major rivers" |  | " |
| 40 | Niger | Ibohamane | 117 | Heusch, 1980 |
| 0.094 | C. I. | Amitioro | 170 | Mathieu, 1971 |
| 0.039 | Chad | Chari | 600,000 | ORSTOM, personal communication |
| 0.149 | " | Logone | 85,000 | " |
| 4.5 | Nigeria | Niger | 1,113,000 | Lal in Lal et al., 1986 |

From D.E. Walling, "The sediment yields of African rivers" in D.E. Walling, S.S.D. Foster, & P. Wurzel (eds.) Challenges in African Hydrology and Water Resources (Proc. Harare Symposium, July 1984). IAHS Publ. no. 144.

## Table B.2 TAMS Soil/Vegetation units subject to soil deposition

| | Rate of soil deposition | | | |
|---|---|---|---|---|
| Soil group | low | (% of area) | high | (% of area) |
| Eroded dunes: | | | DA3 | 1.1 |
| Plains of clayey material: | | | PA1 | 1.2 |
| | | | PA2 | 0.3 |
| | | | PA3 | 0.6 |
| Plains of silty & loamy material: | PL4 | 1.1 | PL3 | 0.3 |
| | PL5 | 2.1 | PL8 | 0.9 |
| | PL6 | 0.5 | PL12 | 0.2 |
| | PL7 | 0.7 | | |
| | PL9 | 2.2 | | |
| Plains of loamy material: | | | PS1 | 1.6 |
| Hydromorphic lands, not flooded: | TH2 | 0.8 | TH1 | 0.2 |
| | TH4 | 0.3 | TH3 | 0.8 |
| | TH7 | 0.3 | TH5 | 0.3 |
| | | | TH8 | 0.4 |
| Flooded lands: | TI7 | 0.4 | TI1 | 1.5 |
| | | | TI2 | 0.4 |
| | | | TI3 | 1.6 |
| | | | TI4 | 0.4 |
| | | | TI5 | 0.1 |
| | | | TI6 | 0.4 |
| Rocky lands: | TR2 | 1.7 | | |
| Special land types: | X1 | 0.1 | X6 | 0.4 |
| TOTAL AREA (%) | | 10.2 | | 12.7 |

## References

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# ANNEX C

## Mali Land and Water Resources:

## A description of the data contained in the atlas prepared by Tippetts, Abbett, McCarthy, and Stratton (TAMS), 1983.

### 1. Rainfall

The TAMS atlas of Mali's land and water resources includes maps showing average annual rainfall, computed from multi-year precipitation records at stations throughout the country. The maps present isohyetes for every 100 mm interval of average precipitation. The isohyetes are roughly parallel from East to West, with increasing rainfall as one moves south away from the Sahara desert. Additional information on ground water is not used here.

### 2. Soil and vegetation

TAMS soil and vegetation maps distinguish 68 units of association in ten broad groups that share common physiographic and/or soil features. The relative importance of the ten groups is shown in Table C.1. Due to the scale of the atlas, map units typically include two or more associated soil/vegetation classes. The relative prevalence of each class within every map unit is indicated on the atlas, in percent of total surface area.

**Table C.1 Surface area of Major Soil/Vegetation Groups**

| Soil/Vegetation group | Surface area (sq. km.) | Percent of total TAMS study area |
|---|---|---|
| Stable dunes | 100,378 | 17.2 |
| Eroded dunes | 58,089 | 10.0 |
| Plains of clayey material | 12,656 | 2.2 |
| Plains of silty & loamy material | 92,140 | 15.8 |
| Plains of loamy material | 21,410 | 3.7 |
| Hydromorphic lands, not flooded | 19,657 | 3.4 |
| Flooded lands | 26,203 | 4.5 |
| Rocky lands | 43,912 | 7.5 |
| Lands underlain by laterite | 123,854 | 21.3 |
| Special land types | 34,259 | 5.9 |
| Inclusions | 50,220 | 8.6 |
| TOTAL | 582,778 | 100.0 |

The soil/vegetation units are described in detail in Volume II of the TAMS atlas. Information used here includes the typical uses, and the range of slope gradients associated with each soil/vegetation unit. The atlas notes which units are used exclusively or predominantly as pasture, those which are cultivated, and the relative intensity of cultivation (i.e. continuous, occasional, or only with a long fallow period).

Topographic information is more limited, with a range of slopes ascribed to certain soil/vegetation units. Five ranges are used to rank map units: "flat to almost flat" (0-2%), "gently sloping" (2-6%), "sloping" (6-13%), "moderately steep" (13-25%), and "steep" (25-55%). TAMS identifies 18 of the 68 map units, covering 37% of the total study area, with slopes over 6%. Eleven of these units (23% of the study area), however, consist of dunes in the North of Mali, and are only occasionally used for millet farming. On more regularly cultivated land, slopes rarely exceed 6%.

## 3. Land Use

Land use data is presented in a separate set of maps. Individual units are distinguished by the type, site, distribution and density of land use; the crops grown in order of importance; and the species of livestock grazing each separate map unit. Not surprisingly, there is a close correspondence between the map units demarcating soil and vegetation resources, and those identifying land use.

Nine types of land use are recognized, within five general classes: pastoral, agro-pastoral, agricultural, bush pasture (i.e., devoid of human settlement and not within pastoral grazing areas), and unused (comprising only one unit of inaccessible plateau, in the far West of Mali). Because we do not consider soil erosion on rangeland, we did not encode any of the data on pastoral land use for this study.

Generally each map unit will correspond to a unique type of land use or site. Where an additional land use type or site is important, within a unit, the atlas designates inclusions. This occurs frequently in the south of Mali, where rain fed cultivation is dominant, but scattered throughout is irrigated farming (principally rice) in small, seasonally-flooded depressions.

To account for the fact that particular land uses do not always occur evenly throughout a map unit, the atlas distinguishes 17 types of agricultural sites. The atlas further distinguishes three possible patterns of distribution of agricultural land use: continuous (contiguous fields), discontinuous (resembling beads along a string), and dispersed (scattered fields separated by non-agricultural land). Twenty principal crops are recognized. For each land use unit, the atlas shows the dominant crops grown, with the first three listed in descending order of importance.

Four categories of agricultural density refer to the percentage of cleared or cultivated land within a map unit. The ranges are 0 - 10%, 11 - 30%, 31 - 60%, and above 60%. For the purposes of this study, we adopted average values of 5, 15, 45, and 80%, respectively. On this basis, the average agricultural density in the study area (BOUGOUNI, BAMAKO, NARA) is 12%, with a maximum of 16% in the Sudanian zone and a minimum of 8% in the Sahelian zone.

Both recently fallowed and cultivated fields are combined in this measure of density, as the two are indistinguishable on LANDSAT images (Vol. II, D-11). Field surveys conducted by the TAMS team revealed no consistent fallow period. In southern Mali, for example, fields adjacent to villages often undergo continuous cultivation, due to the relative ease of transporting manure and other organic fertilizers. More distant fields may be fallowed less than five years or more than twenty, depending on availability of inputs, population pressure, and other local conditions.

For this study, we assume a uniform average crop-fallow ratio of one-to-one. Thus 50% of the cleared or cultivated land identified by TAMS is assumed to be sown in any year. This assumption is based on observations in Mali by recent World Bank missions (Bremen et al. 1988), and on data collected in the preparation of crop budgets in Burkina Faso (Matlon & Fafchamps 1988). If the assumption is correct, we would conclude that the total surface area cultivated in any one year will account for 4 to 8% of all available land.

This range is higher than densities suggested by recent statistics on agricultural production in Mali. The World Bank (Levine 1983) reports 1.8 - 2.0 million hectares under cultivation, in the period when the TAMS atlas was prepared (1979-80), which comprises less than 4% of the surface area receiving over 200 mm annual rainfall. Other sources, however, consider the official statistics on crop acreage to be underestimated, at least in Mali's southern regions (cf. Bremen & Traoré 1987). Our manipulations of the TAMS atlas imply a total cropped surface area of about three million hectares (Table C.2).

### Table C.2 Estimated Agricultural Surface Area and Density of Farming in Mali

Source: TAMS 1983 (based on 1979-80 survey data)

| | STUDY AREA | BOUG (S) | BOUG (N) | BAMAKO (S) | BAMAKO (N) | NARA (S) | NARA (N) |
|---|---|---|---|---|---|---|---|
| SURFACE AREA ALL MAP UNITS (km2) | 187,775 | 36,041 | 29,136 | 35,953 | 34,721 | 25,263 | 26,660 |
| AREA OF MAP UNITS CROPPED/CLEARED | 127,185 | 27,346 | 18,238 | 24,750 | 25,602 | 14,733 | 16,516 |
| WTD AVG DENSITY OF CROP/CLEAR (on map units cropped/cleared) | 18.45% | 16.47% | 17.70% | 23.39% | 21.99% | 15.28% | 12.51% |
| PERCENT TOTAL AREA CROPPED (1:1 crop-fallow ratio) | 5.39% | 6.25% | 5.54% | 8.05% | 8.11% | 4.46% | 3.88% |
| STUDY AREA CROPLAND (km2) | 11,735 | 2,253 | 1,614 | 2,894 | 2,815 | 1,126 | 1,033 |
| COMPARABLE SURFACE AREA | | 1.25 | 1.25 | 2.83 | 3.48 | 3.50 | 4.35 |
| ESTIMATED NATIONAL CROPLAND (km2) | 31,255 | 2,816 | 2,018 | 8,191 | 9,795 | 3,940 | 4,495 |
| WORLD BANK ESTIMATE (1980) | 18,640 | | | | | | |

## References

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# ANNEX D

## Physical Mapping of Soil Erosion in Mali

# LEGEND

| | |
|---|---|
| ▧ | 0 <= EROSION <= 4 TONS/HA/YR |
| ▨ | 4 < EROSION <= 8 TONS/HA/YR |
| ▩ | 8 < EROSION <= 15 TONS/HA/YR |
| ▦ | 15 < EROSION <= 25 TONS/HA/YR |
| ■ | EROSION > 25 TONS/HA/YR |
| ● | CITY |

# ANNEX E

## Crop budgets (Burkina Faso, West Africa)

In calculating erosion impacts, we assume that labor for weeding and harvesting is a variable input, which farmers will adjust in proportion to yields. The household wage assumption is 50% of the prevailing regional wage (see Matlon & Fafchamps, pg. 45). All expenditures and revenues are expressed in 1983 Francs CFA per hectare.

| | SAHEL | SUDAN | N. GUINEA |
|---|---|---|---|
| **SORGHUM** | | | |
| Price (CFA/kg) | 60 | 66 | 46 |
| Crop value | 20,820 | 38,874 | 19,964 |
| Fixed non-labor | 1,405 | 1,731 | 578 |
| Fixed labor | 2,104 | 1,823 | 4,824 |
| Variable labor | 11,051 | 6,741 | 5,789 |
| Return to land | 6,260 | 28,579 | 8,773 |
| **MILLET** | | | |
| Price (CFA/kg) | 53 | 62 | 52 |
| Crop value | 17,755 | 25,544 | 17,680 |
| Fixed non-labor | 477 | 994 | 328 |
| Fixed labor | 668 | 1,408 | 4,612 |
| Variable labor | 7,542 | 6,364 | 5,296 |
| Return to land | 9,068 | 16,778 | 7,444 |
| **MILLET & COWPEA** | | | |
| Price (CFA/kg) | | | |
| Millet | ? | 62 | 52 |
| Cowpea | ? | 84 | 103 |
| Crop value | 19,959 | 21,356 | 12,933 |
| Fixed non-labor | 477 | 1,337 | 873 |
| Fixed labor | 1,022 | 1,712 | 2,312 |
| Variable labor | 8,614 | 4,671 | 5,585 |
| Return to land | 9,846 | 13,636 | 4,163 |

Sahel budget constructed from incomplete data;
fixed costs and prices assumed similar to millet.

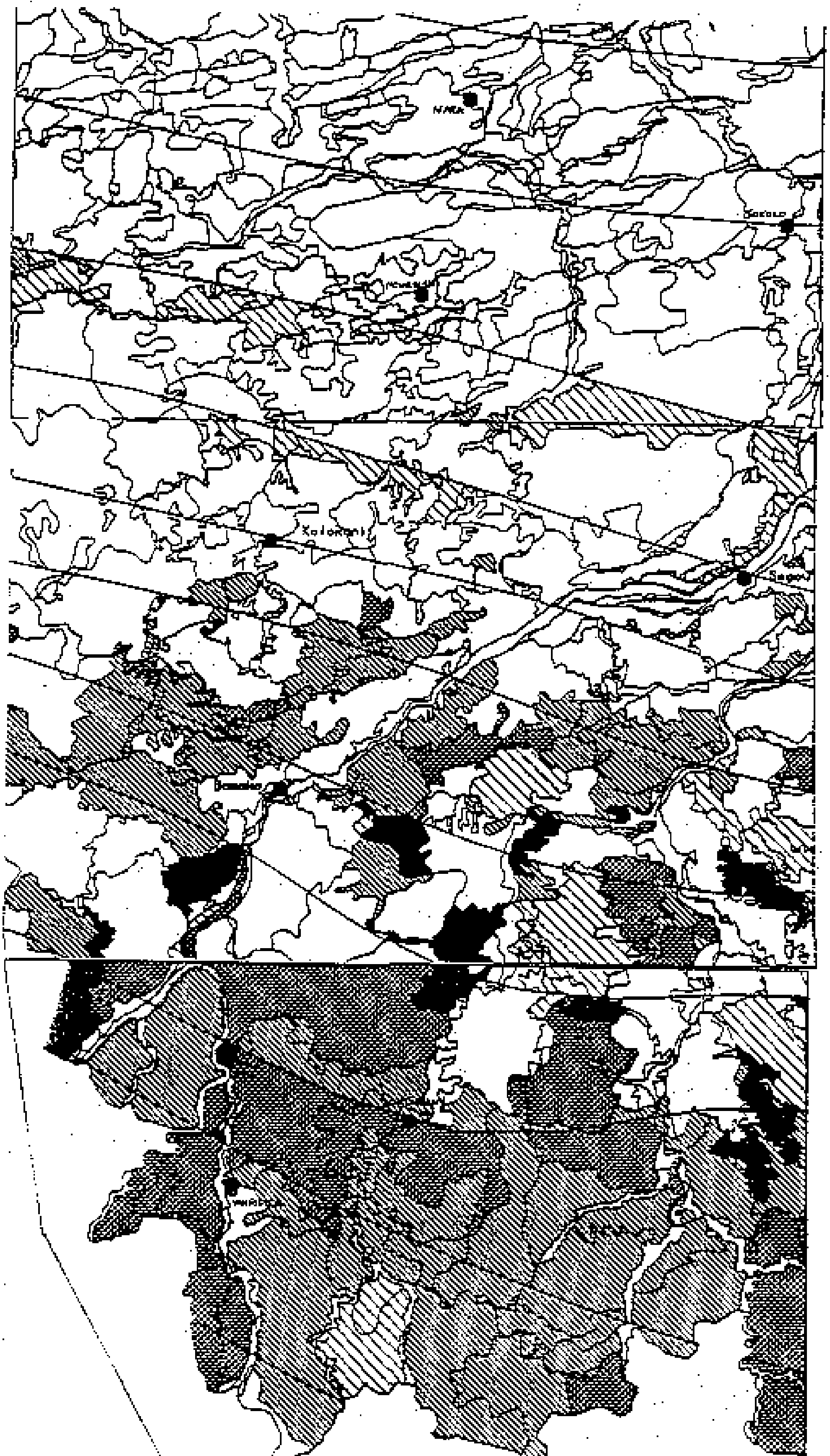
| | SAHEL | SUDAN | N. GUINEA |
|---|---|---|---|
| **MAIZE** | | | |
| Price (CFA/kg) | 88 | 93 | 29 |
| Crop value | 22,352 | 122,016 | 29,029 |
| Fixed non-labor | 2,765 | 5,161 | 8,250 |
| Fixed labor | 12,227 | 6,206 | 9,946 |
| Variable labor | 5,312 | 4,766 | 5,401 |
| Return to land | 2,048 | 105,883 | 5,432 |
| **GROUNDNUT** | | | |
| Price (CFA/kg) | 112 | 112 | 125 |
| Crop value | 21,504 | 35,056 | 45,500 |
| Fixed non-labor | 16,007 | 22,788 | 9,671 |
| Fixed labor | 1,538 | 2,954 | 3,713 |
| Variable labor | 1,493 | 7,539 | 15,979 |
| Return to land | 2,466 | 1,775 | 16,137 |

Sahel budget based on 10% household wage assumption, to ensure positive returns.

| | SAHEL | SUDAN | N. GUINEA |
|---|---|---|---|
| **COTTON** | | | |
| Price (CFA/kg) | | | 62 |
| Crop value | | | 47,306 |
| Fixed non-labor | Only budget available for the Northern Guinea zone, used in all zones. | | 6,588 |
| Fixed labor | | | 2,983 |
| Variable labor | | | 14,533 |
| Return to land | | | 23,202 |

# ANNEX F

## Economic Mapping of Priority Areas for Soil Conservation in Mali



# LEGEND

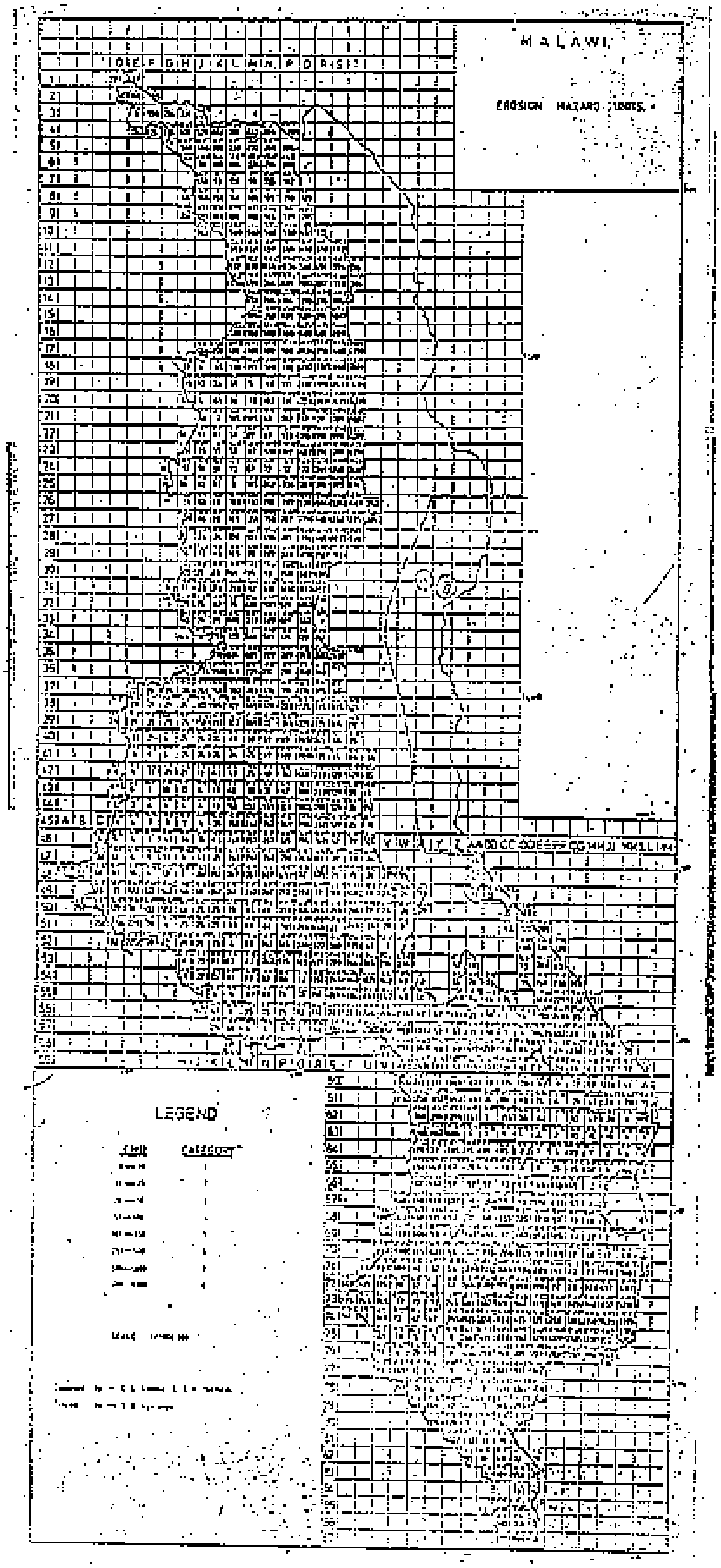
| | |
|---|---|
| ■ | BETA = 0.004 |
| ▩ | BETA = 0.008 |
| ▧ | BETA = 0.010 |
| ▧ | BETA = 0.015 |
| ● | CITY |

**Table F.1 Surface area where erosion losses exceed the cost of conservation**
(r = 10%, t = 10 yrs., 1985 Francs CFA)

| Bougouni, Bamako, Nara | Cost of soil conservation (CFA/ha) | | | |
|---|---|---|---|---|
| | 40,000 | 65,000 | 100,000 | 200,000 |
| Beta = 0.004 | | | | |
| Number of map units | 52 | 6 | 0 | 0 |
| Cultivated surface (ha) | 103,465 | 9,817 | 0 | 0 |
| Beta = 0.006 | | | | |
| Number of map units | 158 | 48 | 6 | 0 |
| Cultivated surface (ha) | 279,410 | 69,987 | 9,817 | 0 |
| Beta = 0.010 | | | | |
| Number of map units | 312 | 175 | 58 | 5 |
| Cultivated surface (ha) | 453,294 | 314,841 | 109,791 | 3,003 |
| Beta = 0.015 | | | | |
| Number of map units | 402 | 309 | 172 | 36 |
| Cultivated surface (ha) | 554,165 | 452,696 | 292,111 | 59,783 |

# ANNEX G

## Mapping Erosion Hazard in Malawi



# ANNEX H

## Estimates of Land Use in Malawi

### H.1 KARONGA LAND USE DATA

| RDP/DISTRICT & SOURCES | TOTAL SURFACE | NAT PARKS & G.R. | COMBINED G.R./F.R. | UNRESERVED SURFACE | TOTAL ARABLE | TOTAL CULT. | SETTLE & INFRAS | DAMBOS & SWAMPS | STEEP SLOPES | COMBINED SWAMPS & SLOPES |
|---|---|---|---|---|---|---|---|---|---|---|
| KARONGA RDP/DISTRICT: | | | | | | | | | | |
| OUR ESTIMATE | 3,379 | 550 | 1,119 | 2,260 | 960 | | | 0 | 1,300 | 1,300 |
| MOA/BASELINE | | | | | 1,168 | 184 | | | | |
| N.P.D.P. | 3,355 | 339 | 489 | 2,866 | 1,073 | 205 | 26 | | | 2,031 |
| CHITIPA RDP/DISTRICT: | | | | | | | | | | |
| OUR ESTIMATE | 4,219 | 621 | 760 | 3,460 | 921 | | | 55 | 2,484 | 2,539 |
| MOA/BASELINE | | | | | 1,360 | 124 | | | | |
| N.P.D.P. | 4,290 | 786 | 1,005 | 3,285 | 1,124 | 160 | 27 | | | 2,841 |
| TOTAL KARONGA ADD: | | | | | | | | | | |
| OUR ESTIMATE | 7,598 | 1,171 | 1,879 | 5,720 | 1,881 | | | 55 | 3,783 | 3,838 |
| MOA/BASELINE | | | | | 2,528 | 308 | | | | |
| N.P.D.P. | 7,645 | 1,125 | 1,494 | 6,151 | 2,197 | 365 | | | | 4,872 |
| STOBBS & JEFFERS | 7,581 | | | | 6,575 | 473 | 64 | 197 | 491 | 688 |
| MOA 3rd Crop 87/88 | | | | | | 663 | | | | |

## H.2 MZUZU LAND USE DATA

| RDP/DISTRICT & SOURCES | TOTAL SURFACE | NAT PARKS & G.R. | COMBINED G.R./F.R. | UNRESERVED SURFACE | TOTAL ARABLE | TOTAL CULT. | SETTLE & INFRAS | DAMBOS & SWAMPS | STEEP SLOPES | COMBINED SWAMPS & SLOPES |
|---|---|---|---|---|---|---|---|---|---|---|
| SOUTH MZIMBA RDP: | | | | | | | | | | |
| OUR ESTIMATE | 3,415 | 0 | 854 | 2,561 | 1,941 | | | 130 | 490 | 620 |
| MOA/BASELINE | 3,311 | | 348 | 2,963 | 2,092 | 333 | | 106 | 775 | 881 |
| N.P.D.P./MZIMBA | 3,360 | | | | 2,144 | 756 | | | | |
| MZADD/CATCHMENT | 3,311 | 0 | 331 | 2,979 | 1,986 | 2,284 | 13 | 99 | 497 | 596 |
| CENTRAL MZIMBA RDP: | | | | | | | | | | |
| OUR ESTIMATE | 3,727 | 0 | 115 | 3,612 | 3,162 | | | 150 | 300 | 450 |
| MOA/BASELINE | 3,926 | | 118 | 3,808 | 3,293 | 542 | | 252 | 253 | 505 |
| N.P.D.P./MZIMBA | 3,846 | | | | 2,907 | 1,994 | | | | |
| MZADD/CATCHMENT | 3,926 | 0 | 118 | 3,808 | 3,298 | 3,455 | 16 | 236 | 275 | 510 |
| NORTH MZIMBA | | | | | | | | | | |
| OUR ESTIMATE | 3,479 | 464 | 594 | 2,886 | 2,346 | | | 0 | 540 | 540 |
| N.P.D.P./MZIMBA | 3,224 | | | | 1,673 | | | | | |
| MZIMBA DISTRICT: | | | | | | | | | | |
| OUR ESTIMATE | 10,622 | 464 | 1,563 | 9,059 | 7,449 | | | 280 | 1,330 | 1,610 |
| N.P.D.P. | 10,430 | 404 | 842 | 9,588 | 6,724 | 1,673 | 102 | | | 4,111 |
| STOBBS & JEFFERS | 10,029 | | | | 9,665 | 1,655 | 99 | 417 | 154 | 571 |
| RUMPHI DISTRICT: | | | | | | | | | | |
| OUR ESTIMATE | 4,496 | 2,238 | 2,263 | 2,233 | 368 | | | 100 | 1,765 | 1,865 |
| N.P.D.P. | 4,767 | 2,545 | 2,551 | 2,216 | 780 | 471 | 23 | | | 1,436 |
| STOBBS & JEFFERS | 4,427 | | | | 4,249 | 107 | 25 | 122 | 91 | 213 |
| RUMPHI/NORTH MZIMBA RDP: | | | | | | | | | | |
| OUR ESTIMATE | 7,975 | 2,702 | 2,857 | 5,118 | 2,713 | | | 100 | 2,305 | 2,405 |
| MOA/BASELINE | 7,312 | | 3,024 | 4,288 | 849 | 211 | | 170 | 3,769 | 3,939 |
| MZADD/CATCHMENT | 7,812 | 2,812 | 2,891 | 4,922 | 2,266 | 3,281 | 156 | 469 | 1,875 | 2,344 |
| NKHATA BAY RDP/DIST.: | | | | | | | | | | |
| OUR ESTIMATE | 4,296 | 0 | 1,236 | 3,060 | 1,030 | | | 0 | 2,031 | 2,031 |
| MOA/BASELINE | 4,427 | | 1,084 | 3,343 | 1,224 | 118 | | 129 | 1,991 | 2,120 |
| MZADD/CATCHMENT | 4,427 | 0 | 1,195 | 3,232 | 841 | 1,859 | 44 | 133 | 1,505 | 1,638 |
| N.P.D.P. | 4,088 | 0 | 1,304 | 2,784 | 488 | 368 | 27 | | | 1,898 |
| STOBBS & JEFFERS | 4,379 | | | | 4,273 | 168 | 35 | 84 | 63 | 147 |
| TOTAL MZUZU ADD: | | | | | | | | | | |
| OUR ESTIMATE | 19,413 | 2,702 | 5,062 | 14,351 | 8,846 | | | 380 | 5,126 | 5,506 |
| MOA/BASELINE | 18,976 | | 4,574 | 14,402 | 7,458 | 1,204 | | 655 | 6,789 | 7,444 |
| MZADD/CATCHMENT | 19,476 | 2,812 | 4,535 | 14,941 | 8,391 | 10,880 | 229 | 936 | 4,152 | 5,088 |
| N.P.D.P. | 19,285 | 2,949 | 4,697 | 14,588 | 7,992 | 2,512 | 152 | | | 7,445 |
| STOBBS & JEFFERS | 18,835 | | | | 18,187 | 1,930 | 159 | 623 | 308 | 931 |
| MOA 3rd Crop 87/88 | | | | | | 1,417 | | | | |

## H.3 KASUNGU LAND USE DATA

| RDP/DISTRICT & SOURCES | TOTAL SURFACE | NAT PARKS & G.R. | COMBINED G.R./F.R. | UNRESERVED SURFACE | TOTAL ARABLE | TOTAL CULT. | SETTLE & INFRAS | DAMBOS & SWAMPS | STEEP SLOPES | COMBINED SWAMPS & SLOPES |
|---|---|---|---|---|---|---|---|---|---|---|
| MCHINJI RDP/DISTRICT: | | | | | | | | | | |
| OUR ESTIMATE | 3,161 | 0 | 238 | 2,923 | 2,064 | | | 827 | 32 | 859 |
| MOA/BASELINE | 3,346 | 0 | 214 | 3,132 | 2,225 | 1,187 | | 555 | 186 | 740 |
| N.P.D.P. | 3,356 | 0 | 192 | 3,164 | 2,085 | 1,361 | 42 | | | 956 |
| KADD/LAND USE 82 | 3,063 | | | | 2,007 | 613 | 56 | 312 | | |
| STOBBS & JEFFERS | 3,217 | | | | 3,099 | 790 | 68 | 363 | 25 | 388 |
| DOWA WEST RDP: | | | | | | | | | | |
| OUR ESTIMATE | 1,695 | 0 | 30 | 1,665 | 1,655 | | | 10 | 0 | 10 |
| MOA/BASELINE | 1,747 | 0 | 23 | 1,724 | 1,348 | 899 | | 139 | 150 | 289 |
| KADD/LAND USE 82 | 1,490 | | | | | 1,014 | 67 | 200 | | |
| DOWA EAST RDP: | | | | | | | | | | |
| OUR ESTIMATE | 1,240 | 0 | 55 | 1,185 | 470 | | | 0 | 715 | 715 |
| MOA/BASELINE | 1,366 | 0 | 48 | 1,318 | 820 | 498 | | 302 | 128 | 430 |
| KADD/LAND USE 82 | 1,428 | | | | | 990 | 58 | 37 | | |
| DOWA DISTRICT: | | | | | | | | | | |
| OUR ESTIMATE | 2,720 | 0 | 85 | 2,635 | 1,910 | | | 10 | 715 | 725 |
| N.P.D.P. | 2,988 | 0 | 43 | 2,945 | 2,236 | 1,217 | 54 | | | 831 |
| NTCHISI DISTRICT: | | | | | | | | | | |
| OUR ESTIMATE | 1,965 | 0 | 210 | 1,755 | 1,240 | | | 0 | 515 | 515 |
| N.P.D.P. | 1,655 | 0 | 97 | 1,558 | 825 | 475 | 18 | | | 767 |
| STOBBS & JEFFERS (INCLUDES DOWA) | 4,659 | | | | 4,556 | 1,039 | 24 | 280 | 10 | 290 |
| OUR EST. (DOWA/NTI) | 4,685 | 0 | 295 | 4,390 | 3,150 | | | 10 | 1,230 | 1,240 |
| NTCHISI RDP: | | | | | | | | | | |
| OUR ESTIMATE | 1,750 | 0 | 210 | 1,540 | 1,025 | | | 0 | 515 | 515 |
| MOA/BASELINE | 1,696 | 0 | 152 | 1,544 | 980 | 539 | | 34 | 445 | 479 |
| KADD/LAND USE 82 | 1,585 | | | | ? | 873 | 42 | 17 | | |

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KASUNGU (continued)

| RDP/DISTRICT & SOURCES | TOTAL SURFACE | NAT PARKS & G.R. | COMBINED G.R./F.R. | UNRESERVED SURFACE | TOTAL ARABLE | TOTAL CULT. | SETTLE & INFRAS | DAMBOS & SWAMPS | STEEP SLOPES | COMBINED SWAMPS & SLOPES |
|---|---|---|---|---|---|---|---|---|---|---|
| KASUNGU RDP/DISTRICT: | | | | | | | | | | |
| OUR ESTIMATE | 7,918 | 2,342 | 2,453 | 5,466 | 4,339 | | | 1,082 | 45 | 1,127 |
| MOA/BASELINE | 5,504 | 7 | 72 | | 4,159 | 1,435 | | 836 | 162 | 998 |
| N.P.D.P. | 7,878 | 2,316 | 2,316 | 5,562 | 4,194 | 2,679 | 49 | | | 909 |
| KADD/LAND USE 82 | 7,616 | | | | 4,855 | 1,824 | 99 | 480 | | |
| STOBBS & JEFFERS | 7,528 | | | | 7,444 | 709 | 39 | 421 | 16 | 437 |
| TOTAL KASUNGU ADD: | | | | | | | | | | |
| OUR ESTIMATE | 15,764 | 2,342 | 2,986 | 12,778 | 9,553 | | | 1,919 | 1,307 | 3,226 |
| MOA/BASELINE | 13,659 | | 507 | 7,719 | 9,532 | 4,558 | | 1,866 | 1,071 | 2,937 |
| N.P.D.P. | 15,877 | 2,316 | 2,648 | 13,229 | 9,340 | 5,732 | 163 | | | 3,463 |
| KADD/LAND USE 82 | 15,182 | | | | 6,862 | 5,313 | 322 | 1,046 | | |
| STOBBS & JEFFERS | 15,404 | | | | 15,099 | 2,538 | 131 | 1,064 | 51 | 1,115 |
| MOA 3rd Crop 87/88 | | | | | | 2,615 | | | | |

## H.4 LILONGWE LAND USE DATA

| RDP/DISTRICT & SOURCES | TOTAL SURFACE | NAT PARKS & G.R. | COMBINED G.R./F.R. | UNRESERVED SURFACE | TOTAL ARABLE | TOTAL CULT. | SETTLE & INFRAS | DAMBOS & SWAMPS | STEEP SLOPES | COMBINED SWAMPS & SLOPES |
|---|---|---|---|---|---|---|---|---|---|---|
| NTCHEU RDP: | | | | | | | | | | |
| OUR ESTIMATE | 2,221 | 0 | 164 | 2,056 | 1,438 | | | 0 | 618 | 618 |
| LADD/DISCUSSION | 2,581 | 0 | 133 | 2,449 | 710 | 892 | | 87 | 1,391 | 1,478 |
| MOA/BASELINE | 2,450 | | | | | 734 | | | | |
| NTCHEU DISTRICT: | | | | | | | | | | |
| OUR ESTIMATE | 3,221 | 0 | 214 | 3,006 | 2,348 | | | 10 | 648 | 658 |
| N.P.D.P. | 3,424 | 0 | 138 | 3,286 | 2,484 | 695 | 82 | | | 805 |
| STOBBS & JEFFERS | 3,474 | | | | 2,752 | 1,068 | 88 | 15 | 517 | 532 |
| THIWI-LIFIDZI RDP: | | | | | | | | | | |
| OUR ESTIMATE | 1,365 | 0 | 281 | 1,104 | 869 | | | 200 | 35 | 235 |
| LADD/DISCUSSION | 1,028 | 0 | 0 | 1,028 | 722 | 718 | | 279 | 18 | 297 |
| MOA/BASELINE | 992 | | | | | 582 | | | | |

LILONGWE (continued)

| RDP/DISTRICT & SOURCES | TOTAL SURFACE | NAT PARKS & G.R. | COMBINED G.R./F.R. | UNRESERVED SURFACE | TOTAL ARABLE | TOTAL CULT. | SETTLE & INFRAS | DAMBOS & SWAMPS | STEEP SLOPES | COMBINED SWAMPS & SLOPES |
|---|---|---|---|---|---|---|---|---|---|---|
| DEDZA RDP: | | | | | | | | | | |
| OUR ESTIMATE | 1,898 | 0 | 615 | 1,283 | 585 | | | 0 | 698 | 698 |
| LADD/DISCUSSION | 1,847 | 0 | 616 | 1,231 | 635 | 675 | | 74 | 682 | 756 |
| MOA/BASELINE | 1,870 | | | | | 330 | | | | |
| DEDZA DISTRICT: | | | | | | | | | | |
| OUR ESTIMATE | 3,862 | 0 | 951 | 2,911 | 1,973 | | | 200 | 738 | 938 |
| N.P.D.P. | 3,624 | 0 | 300 | 3,324 | 1,633 | 959 | 86 | | | 1,409 |
| STOBBS & JEFFERS | 3,924 | | | | 3,278 | 1,569 | 114 | 616 | 450 | 1,066 |
| LILONGWE RDP: | | | | | | | | | | |
| OUR ESTIMATE | 4,822 | 0 | 724 | 4,098 | 3,882 | | | 216 | 0 | 216 |
| LADD/DISCUSSION | 4,681 | 0 | 342 | 4,339 | 3,146 | 2,420 | | 553 | 17 | 570 |
| MOA/BASELINE | 4,680 | | | | | 2,165 | | | | |
| LILONGWE N.E. RDP: | | | | | | | | | | |
| OUR ESTIMATE | 1,460 | 0 | 150 | 1,310 | 1,110 | | | 0 | 200 | 200 |
| LADD/DISCUSSION | 1,581 | 0 | 107 | 1,474 | 688 | 751 | | 150 | 579 | 729 |
| MOA/BASELINE | 1,526 | | | | | 334 | | | | |
| LILONGWE DISTRICT: | | | | | | | | | | |
| OUR ESTIMATE | 6,282 | 0 | 874 | 5,408 | 4,992 | | | 216 | 200 | 416 |
| N.P.D.P. | 6,159 | 0 | 1,161 | 4,998 | 4,884 | 2,108 | 175 | | | 1,236 |
| STOBBS & JEFFERS | 6,265 | | | | 5,544 | 3,228 | 269 | 608 | 338 | 946 |
| TOTAL LILONGWE ADD: | | | | | | | | | | |
| OUR ESTIMATE | 11,786 | 0 | 1,934 | 9,851 | 7,884 | | | 416 | 1,551 | 1,967 |
| LADD/DISCUSSION | 11,718 | 0 | 1,197 | 10,521 | 5,901 | 5,456 | | 1,143 | 2,687 | 3,830 |
| MOA/BASELINE | 11,518 | | | | | 4,145 | | | | |
| MOA 3rd Crop 87/88: | | | | | | 5,215 | | | | |

## H.5 SALIMA LAND USE DATA

| RDP/DISTRICT & SOURCES | TOTAL SURFACE | NAT PARKS & G.R. | COMBINED G.R./F.R. | UNRESERVED SURFACE | TOTAL ARABLE | TOTAL CULT. | SETTLE & INFRAS | DAMBOS & SWAMPS | STEEP SLOPES | COMBINED SWAMPS & SLOPES |
|---|---|---|---|---|---|---|---|---|---|---|
| BWANJE RDP: | | | | | | | | | | |
| OUR ESTIMATE | 2,607 | 0 | 401 | 2,205 | 2,145 | | | 10 | 50 | 60 |
| MOA/BASELINE | 2,274 | 10 | 10 | 2,264 | 2,025 | 333 | 107 | 55 | 77 | 132 |
| SALIMA RDP/DISTRICT: | | | | | | | | | | |
| OUR ESTIMATE | 2,128 | 0 | 102 | 2,027 | 1,887 | | | 0 | 140 | 140 |
| MOA/BASELINE | 2,141 | 100 | 100 | 2,041 | 634 | 355 | 146 | 575 | 685 | 1,260 |
| N.P.D.P. | 2,239 | 0 | 340 | 1,899 | 1,669 | 535 | 40 | | | 206 |
| NKHOTA-KOTA RDP/DIST: | | | | | | | | | | |
| OUR ESTIMATE | 4,342 | 1,763 | 2,098 | 2,244 | 1,780 | | | 0 | 464 | 464 |
| MOA/BASELINE | 4,404 | 2,272 | 2,272 | 2,132 | 603 | 89 | 275 | 313 | 941 | 1,254 |
| N.P.D.P. | 4,259 | 1,802 | 0 | 1,802 | 1,582 | 542 | 30 | | | 1,630 |
| STOBBS & JEFFERS (INCLUDES SALIMA) | 6,725 | | | | 6,520 | 659 | 57 | 194 | 52 | 246 |
| TOTAL SALIMA ADD: | | | | | | | | | | |
| OUR ESTIMATE | 9,076 | 1,763 | 2,601 | 6,475 | 5,812 | | | 10 | 654 | 664 |
| MOA/BASELINE | 8,819 | 2,383 | 2,382 | 6,437 | 3,262 | 776 | 528 | 943 | 1,703 | 2,646 |
| MOA 3rd Crop 87/88 | | | | | | 1,046 | | | | |

## H.6 LIWONDE LAND USE DATA

| RDP/DISTRICT & SOURCES | TOTAL SURFACE | NAT PARKS & G.R. | COMBINED G.R./F.R. | UNRESERVED SURFACE | TOTAL ARABLE | TOTAL CULT. | SETTLE & INFRAS | DAMBOS & SWAMPS | STEEP SLOPES | COMBINED SWAMPS & SLOPES |
|---|---|---|---|---|---|---|---|---|---|---|
| ZOMBA DISTRICT: | | | | | | | | | | |
| OUR ESTIMATE | 2,435 | 0 | 245 | 2,190 | 1,680 | | | 270 | 240 | 510 |
| N.P.D.P. | 2,580 | 0 | 146 | 2,434 | 1,975 | 808 | 65 | | | 477 |
| STOBBS & JEFFERS | 2,176 | | | | 1,831 | 923 | 79 | 207 | 234 | 441 |
| ZOMBA RDP: | | | | | | | | | | |
| OUR ESTIMATE | 3,185 | 0 | 510 | 2,675 | 2,085 | | | 320 | 270 | 590 |
| MOA/BASELINE | 3,321 | | 632 | 2,689 | 1,925 | 734 | | 398 | 366 | 764 |
| BALAKA RDP: | | | | | | | | | | |
| OUR ESTIMATE | 2,145 | 0 | 205 | 1,940 | 1,305 | | | 535 | 100 | 635 |
| MOA/BASELINE | 2,117 | | 10 | 2,107 | 998 | 391 | | 536 | 573 | 1,109 |
| N.P.D.P./MACHINGA | 2,062 | | | | 2,062 | 391 | | | | |
| KAWINGA RDP: | | | | | | | | | | |
| OUR ESTIMATE | 3,128 | 490 | 565 | 2,563 | 1,708 | | | 755 | 100 | 855 |
| MOA/BASELINE | 2,974 | | 525 | 2,449 | 842 | 382 | | 1,265 | 342 | 1,607 |
| N.P.D.P./MACHINGA | 3,012 | | | | 1,631 | 381 | | | | |
| MACHINGA DISTRICT: | | | | | | | | | | |
| OUR ESTIMATE | 5,858 | 390 | 935 | 4,923 | 3,383 | | | 1,310 | 230 | 1,540 |
| N.P.D.P./MACHINGA | 5,964 | 548 | 843 | 5,121 | 4,055 | 1,102 | 101 | 959 | 393 | 1,352 |
| STOBBS & JEFFERS | 6,149 | | | | 5,491 | 1,567 | 61 | 995 | 479 | 1,474 |
| MANGOCHI RDP: | | | | | | | | | | |
| OUR ESTIMATE | 3,303 | 86 | 1,198 | 2,105 | 1,329 | | | 355 | 421 | 776 |
| NAMWERA RDP: | | | | | | | | | | |
| OUR ESTIMATE | 2,009 | 0 | 775 | 1,234 | 964 | | | 0 | 270 | 270 |
| NAMWERA/MANGOCHI RDP: | | | | | | | | | | |
| OUR ESTIMATE | 5,311 | 86 | 1,973 | 3,338 | 2,293 | | | 355 | 691 | 1,046 |
| MOA/BASELINE | 5,208 | | 1,258 | 3,950 | 2,146 | 585 | | 453 | 1,351 | 1,804 |
| MANGOCHI DISTRICT: | | | | | | | | | | |
| OUR ESTIMATE | 6,504 | 186 | 2,369 | 4,135 | 3,044 | | | 385 | 706 | 1,091 |
| N.P.D.P. | 6,272 | 94 | 1,506 | 4,766 | 3,726 | 1,136 | 78 | | | 1,528 |
| STOBBS & JEFFERS | 6,527 | | | | 5,360 | 1,701 | 91 | 203 | 988 | 1,191 |
| LIWONDE ADD | | | | | | | | | | |
| OUR ESTIMATE | 13,769 | 576 | 3,253 | 10,516 | 7,391 | | | 1,965 | 1,161 | 3,126 |
| MOA/BASELINE | 13,619 | | 2,425 | 11,194 | 5,911 | 2,091 | | 2,652 | 2,631 | 5,283 |
| MOA 3rd Crop 87/88 | | | | | | 3,057 | | | | |

## H.7 BLANTYRE LAND USE DATA

| RDP/DISTRICT & SOURCES | TOTAL SURFACE | NAT PARKS & G.R. | COMBINED G.R./F.R. | UNRESERVED SURFACE | TOTAL ARABLE | TOTAL CULT. | SETTLE & INFRAS | DAMBOS & SWAMPS | STEEP SLOPES | COMBINED SWAMPS & SLOPES |
|---|---|---|---|---|---|---|---|---|---|---|
| **MWANZA RDP/DISTRICT:** | | | | | | | | | | |
| OUR ESTIMATE | 2,281 | 45 | 167 | 2,114 | 1,315 | | | 0 | 799 | 799 |
| BLADD/BASIC FACTS | 2,295 | | 140 | | 975 | 297 | | 20 | 1,134 | 1,154 |
| L.R.E.P. | 2,295 | | 82 | 2,187 | | 626 | 26 | 12 | | |
| MOA/BASELINE | 2,290 | | 140 | | 1,410 | 132 | | 20 | 720 | 740 |
| N.P.D.P. | 2,295 | 245 | 327 | | 1,621 | 170 | 26 | | | 670 |
| **BLANTYRE DISTRICT:** | | | | | | | | | | |
| OUR ESTIMATE | 2,077 | 10 | 452 | 1,625 | 1,245 | | | 0 | 380 | 380 |
| L.R.E.P. | 2,012 | | 64 | 1,808 | | 768 | 140 | 5 | | |
| N.P.D.P. | 2,012 | 0 | 64 | | 1,365 | 341 | 141 | | | 500 |
| STOBBS & JEFFERS (INCLUDES MWANZA) | 4,327 | | | | 3,161 | 1,156 | 129 | 25 | 915 | 940 |
| **CHIRADZULU DISTRICT:** | | | | | | | | | | |
| OUR ESTIMATE | 760 | 0 | 15 | 745 | 660 | | | 0 | 85 | 85 |
| N.P.D.P. | 767 | 0 | 11 | | 713 | 339 | 33 | | | 108 |
| **THYOLO DISTRICT:** | | | | | | | | | | |
| OUR ESTIMATE | 1,701 | 0 | 135 | 1,566 | 615 | | | 0 | 951 | 951 |
| N.P.D.P. | 1,715 | 0 | 59 | | 918 | 685 | 55 | | | 710 |
| **CHIRADZULU & THYOLO** | | | | | | | | | | |
| OUR ESTIMATE | 2,461 | 0 | 150 | 2,311 | 1,275 | | | 0 | 1,036 | 1,036 |
| L.R.E.P. | 2,482 | | 70 | 2,324 | | 1,885 | 88 | 0 | | |
| N.P.D.P. | 2,482 | 0 | 70 | | 1,631 | 1,024 | 88 | | | 818 |
| STOBBS & JEFFERS | 2,214 | | | | 1,938 | 1,328 | 112 | 2 | 112 | 114 |
| **SHIRE HIGHLANDS RDP:** | | | | | | | | | | |
| OUR ESTIMATE | 4,538 | 10 | 592 | 3,936 | 2,520 | | | 0 | 1,416 | 1,416 |
| BLADD/BASIC FACTS | 4,503 | | 75 | | 1,805 | 1,805 | | 24 | 2,371 | 2,395 |
| L.R.E.P. | 4,494 | | 134 | 4,132 | | 2,653 | 228 | 5 | | |
| MOA/BASELINE | 4,493 | | 75 | | 3,347 | 1,447 | 234 | 24 | 803 | 827 |
| N.P.D.P. | 4,494 | 0 | 134 | | 2,996 | 1,365 | 229 | | | 1,318 |

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BLANTYRE (continued)

| RDP/DISTRICT & SOURCES | TOTAL SURFACE | NAT PARKS & G.R. | COMBINED G.R./F.R. | UNRESERVED SURFACE | TOTAL ARABLE | TOTAL CULT. | SETTLE & INFRAS | DAMBOS & SWAMPS | STEEP SLOPES | COMBINED SWAMPS & SLOPES |
|---|---|---|---|---|---|---|---|---|---|---|
| PHALOMBE RDP: | | | | | | | | | | |
| OUR ESTIMATE | 1,385 | 0 | 110 | 1,276 | 1,061 | | | 200 | 15 | 215 |
| BLADD/BASIC FACTS | 1,279 | | 48 | | 516 | 516 | | 172 | 519 | 691 |
| L.R.E.P. | 1,279 | | 96 | 1,159 | | 665 | 24 | 89 | | |
| MULANJE RDP: | | | | | | | | | | |
| OUR ESTIMATE | 2,109 | 0 | 574 | 1,535 | 1,470 | | | 0 | 65 | 65 |
| BLADD/BASIC FACTS | 1,540 | | 586 | | 341 | 971 | | 4 | 555 | 558 |
| L.R.E.P. | 2,171 | | 482 | 1,634 | | 1,142 | 55 | 0 | | |
| MULANJE DISTRICT: | | | | | | | | | | |
| OUR ESTIMATE | 3,494 | 0 | 684 | 2,810 | 2,530 | | | 200 | 80 | 280 |
| BLADD/BASIC FACTS | 2,819 | | 635 | | 857 | 1,487 | | 176 | 1,074 | 1,249 |
| L.R.E.P. | 3,450 | | 578 | | | 1,807 | 79 | 89 | | |
| MOA/BASELINE | 3,450 | | 635 | | 2,337 | 1,036 | | 230 | 176 | 406 |
| N.P.D.P. | 3,450 | 0 | 578 | | 2,500 | 876 | 79 | | | 675 |
| STOBBS & JEFFERS | 3,377 | | | | 2,599 | 1,345 | 137 | 153 | 608 | 761 |
| BLANTYRE ADD: | | | | | | | | | | |
| OUR ESTIMATE | 10,313 | 55 | 1,398 | 8,860 | 6,365 | | | 200 | 2,295 | 2,495 |
| BLADD/BASIC FACTS | 9,617 | | 850 | | 3,636 | 3,589 | | 220 | 4,579 | 4,799 |
| L.R.E.P. | 10,239 | | 794 | 6,319 | | 5,086 | 333 | 106 | | |
| MOA/BASELINE | 10,233 | | 850 | | 7,094 | 2,615 | 234 | 274 | 1,699 | 1,973 |
| N.P.D.P. | 10,239 | 245 | 1,039 | | 7,117 | 2,411 | 334 | | | 2,663 |
| STOBBS & JEFFERS | 9,918 | | | | 7,698 | 3,829 | 378 | 180 | 1,635 | 1,815 |
| MOA 3rd Crop 87/88 | | | | | | 3,187 | | | | |

## H.8 NGABU LAND USE DATA

| RDP/DISTRICT & SOURCES | TOTAL SURFACE | NAT PARKS & G.R. | COMBINED G.R./F.R. | UNRESERVED SURFACE | TOTAL ARABLE | TOTAL CULT. | SETTLE & INFRAS | DAMBOS & SWAMPS | STEEP SLOPES | COMBINED SWAMPS & SLOPES |
|---|---|---|---|---|---|---|---|---|---|---|
| NSANJE RDP/DISTRICT: | | | | | | | | | | |
| OUR ESTIMATE | 1,988 | 355 | 149 | 1,485 | 810 | | | 105 | 550 | 655 |
| MOA/NADD | 1,933 | | | | 994 | 478 | | | | |
| 'OVERSTOCKING' | 1,931 | | 1,032 | 900 | | 503 | 41 | 286 | | |
| MOA/BASELINE | 1,931 | 479 | 794 | 658 | 958 | 266 | | | | |
| N.P.D.P. | 1,942 | 348 | 262 | 1,332 | 864 | 338 | 33 | | | 728 |
| STOBBS & JEFFERS | 2,047 | | | | 1,534 | 322 | 55 | 332 | 395 | 727 |
| CHIKWAWA RDP/DISTRICT: | | | | | | | | | | |
| OUR ESTIMATE | 4,702 | 1,765 | 143 | 2,793 | 1,637 | | | 895 | 261 | 1,156 |
| MOA/NADD | 4,821 | | | | 2,132 | 1,526 | | | | |
| 'OVERSTOCKING' | 4,821 | | 3,062 | 1,759 | | 1,199 | 118 | 431 | | |
| MOA/BASELINE | 4,720 | 972 | 1,455 | 2,293 | 2,283 | 733 | | | | |
| N.P.D.P. | 4,755 | 1,426 | 0 | 3,329 | 2,339 | 899 | 49 | | | 777 |
| STOBBS & JEFFERS | 5,211 | | | | 3,817 | 839 | 58 | 351 | 1,217 | 1,568 |
| NGABU ADD: | | | | | | | | | | |
| OUR ESTIMATE | 6,689 | 2,120 | 292 | 4,278 | 2,447 | | | 1,000 | 811 | 1,811 |
| MOA/NADD | 6,755 | | | | 3,126 | 2,005 | | | | |
| 'OVERSTOCKING' | 6,753 | | 4,094 | | | 1,702 | 159 | 717 | | |
| MOA/BASELINE | 6,651 | 1,450 | 2,249 | 2,951 | 3,241 | 998 | | | | |
| N.P.D.P. | 6,697 | 1,774 | 262 | 4,661 | 3,203 | 1,237 | 82 | | | 1,505 |
| STOBBS & JEFFERS | 7,258 | | | | 5,351 | 1,161 | 113 | 683 | 1,612 | 2,295 |
| L.R.E.P. | 6,840 | 1,900 | 330 | 4,610 | 3,940 | 1,985 | | 640 | | |
| MOA 3rd CROP 87/88 | | | | | | 1,018 | | | | |

## LAND USE DATA SOURCES

| | |
|---|---|
| MOA/BASELINE: | Long Term Planning Exercise, Planning Baseline Tables on ADD and RDP Levels, 1983. |
| N.P.D.P.: | National Physical Development Plan, 1986. Vol. II, Tables 6.2, 6.3b. |
| STOBBS & JEFFERS: | Stobbs, A.R. & J.N.R. Jeffers (ed. I. Anderson). 1985. Land Use Survey of Malaiw, 1965-67, Annexe 1: Land Use Class, by administrative districts. |
| MOA 3rd Crop 87/88: | Planning Division, Ministry of Agriculture, 3rd Crop Estimate 1987/88 (data tables). |
| N.P.D.P./MZIMBA: | Mzimba District Physical Development Plan, 1986. Tables 1 and 2. |
| MZADD/CATCHMENT: | Kandaya, H.L.J. & M.K. Mwanyongo. 1990. Catchment conservation programmes in MZADD, Tables 2 and 3. |
| KADD/LAND USE 82: | Land Use Cover Classification, Kasungu ADD, 1982. Tables 9-13. |
| LADD/DISCUSSION: | Agricultural and forestry issues in Lilongwe Agricultural Development Division, 1990. Table 1. |
| N.P.D.P./MACHINGA: | Machinga District Physical Development Plan, 1986. Tables 2 and 3. |
| BLADD/BASIC FACTS: | Basic facts and figures, BLADD, 1987. Table 1. |
| L.R.E.P.: | Land Resources Appraisal of Blantyre Agricultural Development Division, 1989. Tables 4 and 11;<br>Land Resources Appraisal of Ngabu Agricultural Development Division, 1989. Tables 5.1 and 5.2. |
| MOA/NADD: | Raw data provided by Land Husbandry Unit, Ngabu Agricultural Development Division, 8/90. |
| 'OVERSTOCKING': | Overstocking and Land Degradation in Ngabu ADD, 1989. Table I. |

# ANNEX I

## Estimates of Soil Erosion and Yield Loss in Malawi

### I.1 SOIL AND YIELD LOSS ON GROSS ARABLE LAND, BY DISTRICT

| DISTRICT | TOTAL SURFACE (km2) | GROSS ARABLE (km2) | EST. AVG. SOIL LOSS (t/ha/yr) | WEIGHTED AVERAGE YIELD LOSS (%) | | | | |
|---|---|---|---|---|---|---|---|---|
| | | | | β=.002 | .004 | .006 | .010 | .015 |
| CHITIPA | 4,219 | 921 | 24 | 4.6% | 9.0% | 13.1% | 20.6% | 28.9% |
| KARONGA | 3,379 | 960 | 33 | 6.4% | 12.4% | 18.0% | 28.1% | 38.9% |
| NKHATA BAY | 4,296 | 1,030 | 43 | 8.1% | 15.6% | 22.4% | 34.4% | 46.7% |
| RUMPHI | 4,496 | 368 | 16 | 3.2% | 6.2% | 9.1% | 14.6% | 21.0% |
| MZIMBA | 10,622 | 7,449 | 19 | 3.8% | 7.4% | 10.8% | 17.2% | 24.4% |
| NORTHERN REGION | 27,011 | 10,727 | 23 | 4.5% | 8.7% | 12.7% | 20.0% | 28.1% |
| KASUNGU | 7,918 | 4,339 | 16 | 3.1% | 6.1% | 9.0% | 14.3% | 20.5% |
| NKHOTA-KOTA | 4,342 | 1,747 | 17 | 3.3% | 6.5% | 9.5% | 15.3% | 21.9% |
| NTCHISI | 1,965 | 1,240 | 27 | 5.2% | 10.2% | 14.8% | 23.3% | 32.5% |
| DOWA | 2,720 | 1,910 | 28 | 5.4% | 10.5% | 15.3% | 24.0% | 33.4% |
| SALIMA | 2,128 | 1,887 | 11 | 2.2% | 4.4% | 6.5% | 10.5% | 15.3% |
| LILONGWE | 6,282 | 4,992 | 18 | 3.5% | 6.9% | 10.1% | 16.2% | 23.1% |
| MCHINJI | 3,161 | 2,064 | 17 | 3.3% | 6.5% | 9.5% | 15.3% | 21.8% |
| DEDZA | 3,862 | 1,973 | 22 | 4.2% | 8.2% | 12.0% | 19.0% | 26.8% |
| NTCHEU | 3,221 | 2,348 | 29 | 5.6% | 10.7% | 15.6% | 24.3% | 33.7% |
| CENTRAL REGION | 35,598 | 22,499 | 20 | 3.8% | 7.5% | 10.9% | 17.3% | 24.6% |
| MANGOCHI | 6,504 | 3,044 | 15 | 3.0% | 5.9% | 8.7% | 13.9% | 20.0% |
| MACHINGA | 5,858 | 3,383 | 10 | 1.9% | 3.7% | 5.5% | 9.0% | 13.1% |
| ZOMBA | 2,435 | 1,680 | 17 | 3.3% | 6.5% | 9.5% | 15.1% | 21.5% |
| CHIRADZULU | 760 | 660 | 39 | 7.5% | 14.4% | 20.7% | 31.9% | 43.4% |
| BLANTYRE | 2,077 | 1,245 | 32 | 6.1% | 11.8% | 17.1% | 26.5% | 36.4% |
| MWANZA | 2,281 | 1,315 | 20 | 3.9% | 7.6% | 11.2% | 17.7% | 24.9% |
| THYOLO | 1,701 | 615 | 34 | 6.6% | 12.7% | 18.4% | 28.6% | 39.5% |
| MULANJE | 3,494 | 2,530 | 29 | 5.5% | 10.6% | 15.3% | 23.9% | 33.0% |
| CHIKWAWA | 4,702 | 1,637 | 18 | 3.5% | 6.9% | 10.0% | 16.0% | 22.7% |
| NSANJE | 1,988 | 810 | 14 | 2.7% | 5.2% | 7.7% | 12.4% | 17.7% |
| SOUTHERN REGION | 31,798 | 16,919 | 20 | 3.8% | 7.4% | 10.8% | 17.1% | 24.1% |
| MALAWI | 94,407 | 50,145 | 20 | 4.0% | 7.7% | 11.3% | 17.8% | 25.2% |

## I.2 SOIL AND YIELD LOSS ON GROSS ARABLE LAND, BY ADD

| AGRICULTURAL DEVELOPMENT DIVISION | TOTAL SURFACE (km2) | GROSS ARABLE (km2) | CULTIVATED AREA Base (km2) | CULTIVATED AREA High (km2) | EST. AVG. SOIL LOSS (t/ha/yr) | WEIGHTED AVERAGE YIELD LOSS (%) $\beta$=.002 | .004 | .006 | .010 | .015 |
|---|---|---|---|---|---|---|---|---|---|---|
| KARONGA | 7,598 | 1,881 | 663 | N.A. | 29 | 5.5% | 10.7% | 15.6% | 24.4% | 34.0% |
| MZUZU | 19,413 | 8,846 | 1,417 | 2,512 | 22 | 4.3% | 8.4% | 12.2% | 19.3% | 27.1% |
| KASUNGU | 15,764 | 9,553 | 2,615 | 5,732 | 20 | 3.9% | 7.6% | 11.1% | 17.6% | 24.9% |
| LILONGWE | 11,786 | 7,884 | 5,215 | 5,456 | 22 | 4.2% | 8.3% | 12.1% | 19.1% | 26.9% |
| SALIMA | 9,076 | 5,779 | 1,046 | N.A. | 16 | 3.1% | 6.0% | 8.8% | 14.1% | 20.2% |
| LIWONDE | 13,769 | 7,391 | 3,057 | N.A. | 13 | 2.6% | 5.0% | 7.4% | 11.9% | 17.1% |
| BLANTYRE | 10,313 | 6,365 | 3,187 | 5,086 | 29 | 5.6% | 10.8% | 15.7% | 24.4% | 33.7% |
| NGABU | 6,689 | 2,447 | 1,018 | 2,005 | 17 | 3.2% | 6.3% | 9.3% | 14.8% | 21.0% |
| MALAWI | 94,407 | 50,146 | 18,218 | 25,556 | 20 | 4.0% | 7.7% | 11.3% | 17.9% | 25.2% |

Notes:
1. ADD, regional and national soil and yield loss weighted by gross arable area.
2. Baseline estimate of cultivated area is MOA 1987/88 3rd crop estimate. Higher estimates are: NADD and BLADD from LREP, LADD from Environment Discussion Paper, KADD and MZADD from NPDP.

### I.2.1 KARONGA ADD: SOIL AND YIELD LOSS ON GROSS ARABLE LAND

| RURAL DEVELOPMENT PROJECT (RDP) | TOTAL SURFACE (km2) | GROSS ARABLE (km2) | EST. AVG. SOIL LOSS (t/ha/yr) | WEIGHTED AVERAGE YIELD LOSS (%) $\beta$=.002 | .004 | .006 | .010 | .015 |
|---|---|---|---|---|---|---|---|---|
| KARONGA RDP | 3,379 | 960 | 33 | 6.4% | 12.4% | 18.0% | 28.1% | 38.9% |
| CHITIPA RDP | 4,219 | 921 | 24 | 4.6% | 9.0% | 13.1% | 20.6% | 28.9% |
| KARONGA ADD | 7,598 | 1,881 | 29 | 5.5% | 10.7% | 15.6% | 24.4% | 34.0% |

### I.2.2 MZUZU ADD: SOIL AND YIELD LOSS ON GROSS ARABLE LAND

| RURAL DEVELOPMENT PROJECT (RDP) | TOTAL SURFACE (km2) | GROSS ARABLE (km2) | EST. AVG. SOIL LOSS (t/ha/yr) | WEIGHTED AVERAGE YIELD LOSS (%) $\beta$=.002 | .004 | .006 | .010 | .015 |
|---|---|---|---|---|---|---|---|---|
| SOUTH MZIMBA RDP | 3,415 | 1,941 | 24 | 4.7% | 9.1% | 13.2% | 20.8% | 29.1% |
| CENTRAL MZIMBA RDP | 3,727 | 3,162 | 16 | 3.2% | 6.2% | 9.2% | 14.7% | 21.0% |
| RUMPHI/N. MZIMBA RDP | 7,975 | 2,713 | 20 | 3.9% | 7.6% | 11.2% | 17.8% | 25.3% |
| NKHATA BAY RDP | 4,296 | 1,030 | 43 | 8.1% | 15.6% | 22.4% | 34.4% | 46.7% |
| MZUZU ADD | 19,413 | 8,846 | 22 | 4.3% | 8.4% | 12.2% | 19.3% | 27.1% |

## I.2.3 KASUNGU ADD: SOIL AND YIELD LOSS ON GROSS ARABLE LAND

| RURAL DEVELOPMENT PROJECT (RDP) | TOTAL SURFACE (km2) | GROSS ARABLE (km2) | EST. AVG. SOIL LOSS (t/ha/yr) | WEIGHTED AVERAGE YIELD LOSS (%) | | | | |
|---|---|---|---|---|---|---|---|---|
| | | | | β=.002 | .004 | .006 | .010 | .015 |
| MCHINJI RDP | 3,161 | 2,064 | 17 | 3.3% | 6.5% | 9.5% | 15.3% | 21.8% |
| DOWA WEST RDP | 1,695 | 1,655 | 25 | 5.0% | 9.6% | 14.1% | 22.2% | 31.2% |
| DOWA EAST RDP | 1,240 | 470 | 36 | 6.9% | 13.3% | 19.3% | 29.9% | 41.1% |
| NTCHISI RDP | 1,750 | 1,025 | 27 | 5.2% | 10.1% | 14.8% | 23.2% | 32.4% |
| KASUNGU RDP | 7,918 | 4,339 | 16 | 3.1% | 6.1% | 9.0% | 14.3% | 20.5% |
| KASUNGU ADD | 15,764 | 9,553 | 20 | 3.9% | 7.6% | 11.1% | 17.6% | 24.9% |

## I.2.4 LILONGWE ADD: SOIL AND YIELD LOSS ON GROSS ARABLE LAND

| RURAL DEVELOPMENT PROJECT (RDP) | TOTAL SURFACE (km2) | GROSS ARABLE (km2) | EST. AVG. SOIL LOSS (t/ha/yr) | WEIGHTED AVERAGE YIELD LOSS (%) | | | | |
|---|---|---|---|---|---|---|---|---|
| | | | | β=.002 | .004 | .006 | .010 | .015 |
| NTCHEU RDP | 2,221 | 1,438 | 32 | 6.2% | 11.9% | 17.3% | 26.9% | 37.1% |
| THIWI-LIFIDZI RDP | 1,385 | 869 | 20 | 3.9% | 7.7% | 11.2% | 17.8% | 25.3% |
| DEDZA RDP | 1,898 | 585 | 32 | 6.1% | 11.8% | 17.2% | 26.8% | 37.2% |
| LILONGWE RDP | 4,822 | 3,882 | 16 | 3.1% | 6.0% | 8.8% | 14.2% | 20.4% |
| LILONGWE N.E. RDP | 1,460 | 1,110 | 27 | 5.1% | 10.0% | 14.6% | 23.0% | 32.3% |
| LILONGWE ADD | 11,786 | 7,884 | 22 | 4.2% | 8.3% | 12.1% | 19.1% | 26.9% |

## I.2.5 SALIMA ADD: SOIL AND YIELD LOSS ON GROSS ARABLE LAND

| RURAL DEVELOPMENT PROJECT (RDP) | TOTAL SURFACE (km2) | GROSS ARABLE (km2) | EST. AVG. SOIL LOSS (t/ha/yr) | WEIGHTED AVERAGE YIELD LOSS (%) | | | | |
|---|---|---|---|---|---|---|---|---|
| | | | | β=.002 | .004 | .006 | .010 | .015 |
| BWANJE RDP | 2,607 | 2,145 | 18 | 3.6% | 7.0% | 10.3% | 16.4% | 23.2% |
| SALIMA RDP | 2,128 | 1,887 | 11 | 2.2% | 4.4% | 6.5% | 10.5% | 15.3% |
| NKHOTA-KOTA RDP | 4,342 | 1,747 | 17 | 3.3% | 6.5% | 9.5% | 15.3% | 21.9% |
| SALIMA ADD | 9,076 | 5,779 | 16 | 3.1% | 6.0% | 8.8% | 14.1% | 20.2% |

### I.2.6 LIWONDE ADD: SOIL AND YIELD LOSS ON GROSS ARABLE LAND

| RURAL DEVELOPMENT PROJECT (RDP) | TOTAL SURFACE (km2) | GROSS ARABLE (km2) | EST. AVG. SOIL LOSS (t/ha/yr) | WEIGHTED AVERAGE YIELD LOSS (%) | | | | |
|---|---|---|---|---|---|---|---|---|
| | | | | β=.002 | .004 | .006 | .010 | .015 |
| ZOMBA RDP | 3,185 | 2,085 | 15 | 3.0% | 5.8% | 8.6% | 13.7% | 19.5% |
| BALAKA RDP | 2,145 | 1,305 | 10 | 1.9% | 3.8% | 5.6% | 9.1% | 13.3% |
| KAWINGA RDP | 3,128 | 1,708 | 10 | 1.9% | 3.8% | 5.7% | 9.3% | 13.6% |
| MANGOCHI RDP | 3,303 | 1,329 | 13 | 2.6% | 5.1% | 7.5% | 12.1% | 17.5% |
| NAMWERA RDP | 2,009 | 964 | 18 | 3.5% | 6.9% | 10.1% | 16.1% | 22.9% |
| LIWONDE ADD | 13,769 | 7,391 | 13 | 2.6% | 5.0% | 7.4% | 11.9% | 17.1% |

### I.2.7 BLANTYRE ADD: SOIL AND YIELD LOSS ON GROSS ARABLE LAND

| RURAL DEVELOPMENT PROJECT (RDP) | TOTAL SURFACE (km2) | GROSS ARABLE (km2) | EST. AVG. SOIL LOSS (t/ha/yr) | WEIGHTED AVERAGE YIELD LOSS (%) | | | | |
|---|---|---|---|---|---|---|---|---|
| | | | | β=.002 | .004 | .006 | .010 | .015 |
| MWANZA RDP | 2,281 | 1,315 | 20 | 3.9% | 7.6% | 11.2% | 17.7% | 24.9% |
| SHIRE HIGHLANDS RDP | 4,538 | 2,520 | 34 | 6.6% | 12.7% | 18.4% | 28.4% | 39.0% |
| PHALOMBE RDP | 1,385 | 1,061 | 24 | 4.6% | 9.0% | 13.1% | 20.5% | 28.5% |
| MULANJE RDP | 2,109 | 1,470 | 32 | 6.1% | 11.8% | 17.0% | 26.3% | 36.2% |
| BLANTYRE ADD | 10,313 | 6,365 | 29 | 5.6% | 10.8% | 15.7% | 24.4% | 33.7% |

### I.2.8 NGABU ADD: SOIL AND YIELD LOSS ON GROSS ARABLE LAND

| RURAL DEVELOPMENT PROJECT (RDP) | TOTAL SURFACE (km2) | GROSS ARABLE (km2) | EST. AVG. SOIL LOSS (t/ha/yr) | WEIGHTED AVERAGE YIELD LOSS (%) | | | | |
|---|---|---|---|---|---|---|---|---|
| | | | | β=.002 | .004 | .006 | .010 | .015 |
| NSANJE RDP | 1,988 | 810 | 14 | 2.7% | 5.2% | 7.7% | 12.4% | 17.7% |
| CHIKWAWA RDP | 4,702 | 1,637 | 18 | 3.5% | 6.9% | 10.0% | 16.0% | 22.7% |
| NGABU ADD | 6,689 | 2,447 | 17 | 3.2% | 6.3% | 9.3% | 14.8% | 21.0% |

# ANNEX J

## Cropping Patterns, Crop Budgets, Gross and Net Margins in Malawi

### J.1 PERCENT OF CULTIVATED AREA DEVOTED TO EACH CROP

| CROP | KARONGA | MZUZU | KASUNGU | LILONGWE | SALIMA | LIWONDE | BLANTYRE | NGABU | MALAWI |
|---|---|---|---|---|---|---|---|---|---|
| LOCAL MAIZE (-FERT) | 27.1 | 16.2 | 45.3 | 30.9 | 40.9 | 47.9 | 44.2 | 28.2 | 37.3 |
| LOCAL MAIZE (+FERT) | 2.5 | 22.6 | 9.6 | 17.5 | 10.5 | 15.4 | 3.7 | .0 | 12.1 |
| HYBRID MAIZE (+FERT) | 3.1 | 11.4 | 9.9 | 9.4 | 1.1 | .9 | .6 | .7 | 5.5 |
| COMPOSITE MAIZE (+FERT) | 1.7 | 2.9 | 4.5 | 1.3 | 7.3 | .3 | .6 | .0 | 1.9 |
| MAIZE MIXTURES | 14.0 | 11.4 | 4.1 | 14.2 | 4.1 | 12.9 | 19.8 | 4.0 | 12.1 |
| TOTAL MAIZE | 48.4 | 64.5 | 73.4 | 73.3 | 63.9 | 77.4 | 68.9 | 32.9 | 68.8 |
| RICE | 14.2 | .4 | .0 | .0 | 3.6 | 2.9 | 1.8 | 1.6 | 1.6 |
| MILLET | 4.7 | 7.3 | .4 | 1.4 | .8 | .7 | .6 | 17.1 | 2.4 |
| SORGHUM | .2 | .0 | .0 | .0 | .2 | 1.6 | 2.9 | 26.5 | 2.3 |
| ROOTS | 14.6 | 9.6 | 2.0 | 1.4 | 12.5 | 5.8 | 7.4 | .5 | 5.0 |
| GROUNDNUTS (CHALIMBANA) | .1 | 3.2 | 13.1 | 8.4 | 1.0 | 1.4 | .2 | .0 | 4.9 |
| GROUNDNUTS (OTHER) | 4.0 | 5.2 | 1.6 | 3.7 | 5.4 | 5.2 | 3.9 | 1.3 | 3.8 |
| PULSES/BEANS | 10.6 | 9.0 | 3.1 | 6.2 | .4 | 2.8 | 12.9 | 1.1 | 6.1 |
| COTTON | 2.9 | .0 | .0 | .2 | 12.2 | 1.9 | .9 | 19.1 | 2.4 |
| TOBACCO (NDDF) | .0 | .1 | 4.0 | 4.0 | .0 | .3 | .4 | .0 | 1.9 |
| TOBACCO (OTHER) | .0 | .6 | 2.3 | 1.4 | .0 | .0 | .0 | .0 | .8 |
| COFFEE/TEA | .3 | .2 | .2 | .0 | .0 | .0 | .2 | .0 | .1 |
| TOTAL | 100.0 | 100.1 | 100.1 | 100.0 | 100.0 | 100.0 | 100.1 | 100.1 | 100.0 |

Source: ASA 1980/81 to 1985/86 averaged (from NRDP), combined with data from ASA 1987/88 and AES Report No. 55.

Notes:
1. Fertilizer usage from AES Report No. 55; for composite and hybrid maize assume 100% fertilized; for mixtures use same breakdown as for local maize.
2. Breakdown between Chalimbana and other ground-nut varieties from ASA 1987/88; ditto for NNDF vs. other tobaccos; assume 100% of tobacco is fertilized.
3. Malawi average weighted by baseline est. of cultivated area by ADD

## J.2 CROP BUDGETS (AVERAGE ALL AREAS)

| CROP | AES (INFLATED) NET INCOME (K/HA) | AES (INFLATED) GROSS MARGINS (K/HA) | MOA 1989/90 GROSS MARGINS (K/HA) |
|---|---|---|---|
| LOCAL MAIZE (- FERT) | 104 | 175 | 202 |
| LOCAL MAIZE (+FERT) | 82 | 152 | 284 |
| HYBRID MAIZE (+FERT) | 298 | 433 | 414 |
| COMPOSITE MAIZE (+FERT) | 167 | 269 | |
| MAIZE MIXTURES | 342 | 541 | 300 |
| RICE (AVG FAYA & BLUE BONNET) | -145 | 368 | 459 |
| MILLET | | | |
| SORGHUM | -20 | 58 | 62 |
| ROOT CROPS | | | |
| GROUNDNUTS (CHALIMBANA) | 146 | 215 | 222 |
| GROUNDNUTS (OTHER) | 125 | 251 | 351 |
| PULSES/BEANS | | | 91 |
| COTTON | 48 | 278 | 460 |
| TOBACCO (NDDF) | 255 | 740 | 1325 |
| TOBACCO (OTHER) | 26 | 359 | 919 |

Source: Agro-Economic Survey (AES) Report No. 55 (1987) and MOA data tables (1989/90). Both use standard yield figures and official ADMARC prices; AES values are inflated from 1984/85 to 1989/90, using the growth rate of gross margins for each crop, as reported in MOA data tables. Sorghum under MOA is taken from NRDP, table 14 (87/88).

## J.3 COMPOSITE GROSS MARGINS

### AVERAGE CONTRIBUTION OF EACH CROP TO GROSS MARGINS PER HECTARE

| MAJOR CROPS | KARONGA | MZUZU | KASUNGU | LILONGWE | SALIMA | LIWONDE | BLANTYRE | NGABU | MALAWI |
|---|---|---|---|---|---|---|---|---|---|
| LOCAL MAIZE (- FERT) | 54.6 | 32.6 | 91.3 | 62.2 | 82.3 | 96.4 | 89.0 | 56.8 | 75.1 |
| LOCAL MAIZE (+FERT) | 7.1 | 64.3 | 27.3 | 49.8 | 29.9 | 43.9 | 10.6 | .0 | 34.4 |
| HYBRID MAIZE (+FERT) | 12.8 | 47.2 | 41.0 | 39.0 | 4.6 | 3.7 | 2.5 | 2.9 | 22.7 |
| COMPOSITE MAIZE (+FERT) | 4.6 | 7.8 | 12.1 | 3.5 | 19.6 | .8 | 1.6 | .0 | 5.1 |
| MAIZE MIXTURES | 42.0 | 34.2 | 12.3 | 42.6 | 12.3 | 38.7 | 59.4 | 12.0 | 36.4 |
| TOTAL MAIZE | 121.1 | 186.1 | 184.0 | 197.0 | 148.7 | 183.5 | 163.1 | 71.7 | 173.6 |
| RICE | N.A. | N.A. | N.A. | N.A. | N.A. | N.A. | N.A. | N.A. | N.A. |
| MILLET | 2.7 | 4.3 | .2 | .8 | .5 | .4 | .4 | 10.0 | 1.4 |
| SORGHUM | .1 | .0 | .0 | .0 | .1 | .9 | 1.7 | 15.5 | 1.3 |
| ROOTS | N.A. | N.A. | N.A. | N.A. | N.A. | N.A. | N.A. | N.A. | N.A. |
| GROUNDNUTS (CHALIMBANA) | .2 | 7.0 | 29.2 | 18.6 | 2.2 | 3.1 | .4 | .0 | 10.8 |
| GROUNDNUTS (OTHER) | 14.0 | 18.4 | 5.5 | 13.1 | 18.9 | 18.2 | 13.8 | 4.6 | 13.3 |
| PULSES/BEANS | 9.6 | 8.2 | 2.8 | 5.6 | .4 | 2.5 | 11.7 | 1.0 | 5.5 |
| COTTON | 13.3 | .0 | .0 | .9 | 56.2 | 8.7 | 4.1 | 87.9 | 11.1 |
| TOBACCO (NDDF) | .0 | 1.5 | 53.4 | 53.3 | .0 | 4.0 | 5.3 | .0 | 24.7 |
| TOBACCO (OTHER) | .0 | 5.4 | 20.9 | 12.6 | .0 | .0 | .0 | .0 | 7.0 |
| MEAN ALL CROPS (K/HA) | 161 | 231 | 296 | 302 | 227 | 221 | 200 | 191 | 248.7 |

Notes:
1. Gross margins from MOA 1989/90, except composite maize, from from AES Report No. 55, sorghum from NRDP table 14 (87/88).
2. No data for root crops; millet treated as sorghum.
3. Rice is excluded; assumed to incur no erosion losses.
4. Malawi average weighted by baseline estimate of cultivated area.

## J.4 COMPOSITE NET REVENUES

### AVERAGE CONTRIBUTION OF EACH CROP TO NET INCOME PER HECTARE

| MAJOR CROPS | KARONGA | MZUZU | KASUNGU | LILONGWE | SALIMA | LIWONDE | BLANTYRE | NGABU | MALAWI |
|---|---|---|---|---|---|---|---|---|---|
| LOCAL MAIZE (- FERT) | 28.1 | 16.8 | 47.0 | 32.0 | 42.4 | 49.6 | 45.8 | 29.2 | 38.6 |
| LOCAL MAIZE (+FERT) | 2.1 | 18.6 | 7.9 | 14.4 | 8.7 | 12.7 | 3.1 | .0 | 10.0 |
| HYBRID MAIZE (+FERT) | 9.2 | 34.0 | 29.5 | 28.0 | 3.3 | 2.7 | 1.8 | 2.1 | 16.3 |
| COMPOSITE MAIZE (+FERT) | 2.8 | 4.8 | 7.5 | 2.2 | 12.2 | .5 | 1.0 | .0 | 3.1 |
| MAIZE MIXTURES | 47.9 | 39.0 | 14.0 | 48.6 | 14.0 | 44.1 | 67.7 | 13.7 | 41.5 |
| TOTAL MAIZE | 90.1 | 113.2 | 105.9 | 125.2 | 80.5 | 109.7 | 119.4 | 45.0 | 109.6 |
| RICE | N.A. | N.A. | N.A. | N.A. | N.A. | N.A. | N.A. | N.A. | N.A. |
| MILLET | N.A. | N.A. | N.A. | N.A. | N.A. | N.A. | N.A. | N.A. | N.A. |
| SORGHUM | N.A. | N.A. | N.A. | N.A. | N.A. | N.A. | N.A. | N.A. | N.A. |
| ROOTS | N.A. | N.A. | N.A. | N.A. | N.A. | N.A. | N.A. | N.A. | N.A. |
| GROUNDNUTS (CHALIMBANA) | .2 | 4.6 | 19.2 | 12.2 | 1.5 | 2.1 | .3 | .0 | 7.1 |
| GROUNDNUTS (OTHER) | 5.0 | 6.6 | 2.0 | 4.7 | 6.8 | 6.5 | 4.9 | 1.6 | 4.7 |
| PULSES/BEANS | N.A. | N.A. | N.A. | N.A. | N.A. | N.A. | N.A. | N.A. | N.A. |
| COTTON | 1.4 | .0 | .0 | .1 | 5.8 | .9 | .4 | 9.2 | 1.2 |
| TOBACCO (NDDF) | .0 | .3 | 10.3 | 10.3 | .0 | .8 | 1.0 | .0 | 4.7 |
| TOBACCO (OTHER) | .0 | .2 | .6 | .4 | .0 | .0 | .0 | .0 | .2 |
| MEAN ALL CROPS (K/HA) | 97 | 125 | 138 | 153 | 95 | 120 | 126 | 56 | 127.5 |

Notes:
1. Net income from AES Report No. 55.
2. No data for root crops and millet.
3. Rice is excluded; assumed to incur no erosion losses.
4. Sorghum is excluded due to negative net income.
5. Malawi average weighted by baseline estimate of cultivated area.

# ANNEX K

## Estimated Income Foregone due to Soil Erosion in Malawi

### K.1 CURRENT GROSS MARGIN LOSSES

| | KARONGA | MZUZU | KASUNGU | LILONGWE | SALIMA | LIWONDE | BLANTYRE | NGABU | MALAWI |
|---|---|---|---|---|---|---|---|---|---|
| COMP. GROSS MARGIN (K/HA) | 161 | 231 | 296 | 302 | 227 | 221 | 200 | 191 | 248.7 |
| MEAN ANNUAL LOSS (K/HA/YR) | | | | | | | | | |
| Beta = .002 | 9 | 10 | 12 | 13 | 7 | 6 | 11 | 6 | 10 |
| Beta = .004 | 17 | 19 | 22 | 25 | 14 | 11 | 22 | 12 | 20 |
| Beta = .006 | 25 | 28 | 33 | 36 | 20 | 16 | 31 | 18 | 29 |
| Beta = .010 | 39 | 45 | 52 | 58 | 32 | 26 | 49 | 28 | 45 |
| Beta = .015 | 55 | 63 | 74 | 81 | 46 | 38 | 68 | 40 | 64 |
| TOTAL ANNUAL LOSS ('000 K) (base estimate of cultivated area) | | | | | | | | | |
| Beta = .002 | 593 | 1,409 | 3,010 | 6,688 | 724 | 1,727 | 3,585 | 627 | 18,363 |
| Beta = .004 | 1,148 | 2,739 | 5,871 | 13,020 | 1,421 | 3,394 | 6,916 | 1,227 | 35,735 |
| Beta = .006 | 1,667 | 3,996 | 8,592 | 19,018 | 2,090 | 5,002 | 10,013 | 1,800 | 52,178 |
| Beta = .010 | 2,611 | 6,311 | 13,645 | 30,094 | 3,354 | 8,054 | 15,580 | 2,871 | 82,520 |
| Beta = .015 | 3,632 | 8,872 | 19,305 | 42,402 | 4,805 | 11,587 | 21,525 | 4,084 | 116,212 |
| TOTAL ANNUAL LOSS ('000 K) (high estimate of cultivated area) | | | | | | | | | |
| Beta = .002 | 0 | 2,497 | 6,597 | 6,997 | 0 | 0 | 5,721 | 1,236 | 26,092 |
| Beta = .004 | 0 | 4,855 | 12,868 | 13,622 | 0 | 0 | 11,036 | 2,416 | 50,760 |
| Beta = .006 | 0 | 7,083 | 18,832 | 19,897 | 0 | 0 | 15,980 | 3,544 | 74,096 |
| Beta = .010 | 0 | 11,186 | 29,906 | 31,486 | 0 | 0 | 24,864 | 5,655 | 117,115 |
| Beta = .015 | 0 | 15,725 | 42,311 | 44,363 | 0 | 0 | 34,351 | 8,044 | 164,818 |

Note: Use base estimate of cultivated area where no high estimate is available.

## K.2 CAPITALIZED GROSS MARGIN LOSSES

PLANNING HORIZON (years): 10
DISCOUNT RATE: 10.0%

| | KARONGA | MZUZU | KASUNGU | LILONGWE | SALIMA | LIWONDE | BLANTYRE | NGABU | MALAWI |
|---|---|---|---|---|---|---|---|---|---|
| MEAN CAPITALIZED LOSS (K/HA) | | | | | | | | | |
| Beta = .002 | 64 | 71 | 82 | 92 | 49 | 40 | 80 | 44 | 72 |
| Beta = .004 | 124 | 138 | 160 | 178 | 97 | 79 | 155 | 86 | 140 |
| Beta = .006 | 180 | 201 | 235 | 261 | 143 | 117 | 224 | 126 | 205 |
| Beta = .010 | 281 | 318 | 373 | 412 | 229 | 188 | 349 | 202 | 324 |
| Beta = .015 | 391 | 447 | 527 | 581 | 328 | 271 | 483 | 287 | 456 |
| TOTAL CAPITALIZED LOSS ('000 K) (base estimate of cultivated area) | | | | | | | | | |
| Beta = .002 | 4,235 | 10,065 | 21,505 | 47,784 | 5,175 | 12,342 | 25,611 | 4,483 | 131,199 |
| Beta = .004 | 8,199 | 19,570 | 41,948 | 93,022 | 10,149 | 24,246 | 49,409 | 8,765 | 255,309 |
| Beta = .006 | 11,912 | 28,553 | 61,388 | 135,874 | 14,933 | 35,734 | 71,539 | 12,858 | 372,793 |
| Beta = .010 | 18,653 | 45,089 | 97,489 | 215,008 | 23,964 | 57,540 | 111,315 | 20,513 | 589,570 |
| Beta = .015 | 25,948 | 63,386 | 137,926 | 302,943 | 34,333 | 82,784 | 153,785 | 29,181 | 830,285 |

## K.3 CURRENT NET REVENUE LOSSES

| | KARONGA | MZUZU | KASUNGU | LILONGWE | SALIMA | LIWONDE | BLANTYRE | NGABU | MALAWI |
|---|---|---|---|---|---|---|---|---|---|
| COMP. NET REVENUE (K/HA) | 97 | 125 | 138 | 153 | 95 | 120 | 126 | 56 | 127.5 |
| MEAN ANNUAL LOSS (K/HA/YR) | | | | | | | | | |
| Beta = .002 | 5 | 5 | 5 | 6 | 3 | 3 | 7 | 2 | 5 |
| Beta = .004 | 10 | 10 | 10 | 13 | 6 | 6 | 14 | 4 | 10 |
| Beta = .006 | 15 | 15 | 15 | 18 | 8 | 9 | 20 | 5 | 15 |
| Beta = .010 | 24 | 24 | 24 | 29 | 13 | 14 | 31 | 8 | 24 |
| Beta = .015 | 33 | 34 | 34 | 41 | 19 | 21 | 42 | 12 | 33 |

## K.4 CAPITALIZED NET REVENUE LOSSES

PLANNING HORIZON (years): 10
DISCOUNT RATE: 10.0%

| | KARONGA | MZUZU | KASUNGU | LILONGWE | SALIMA | LIWONDE | BLANTYRE | NGABU | MALAWI |
|---|---|---|---|---|---|---|---|---|---|
| MEAN CAPITALIZED LOSS (K/HA) | | | | | | | | | |
| Beta = .002 | 38 | 38 | 38 | 46 | 21 | 22 | 51 | 13 | 38 |
| Beta = .004 | 74 | 75 | 75 | 90 | 40 | 43 | 97 | 25 | 73 |
| Beta = .006 | 108 | 109 | 109 | 132 | 60 | 63 | 141 | 37 | 107 |
| Beta = .010 | 169 | 172 | 174 | 209 | 95 | 102 | 220 | 59 | 168 |
| Beta = .015 | 235 | 242 | 246 | 294 | 137 | 147 | 303 | 84 | 237 |

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# BOOKS

Edward B. Barbier
**Economics, Natural-Resource Scarcity and Development: Conventional and Alternative Views**, Earthscan, London, 1989 (paperback £17.50)

The history of environmental and resource economics is reviewed; then using insights from environmentalism, ecology and thermodynamics, Barbier begins the construction of a new economic approach to the use of natural resources, particularly to the problem of environmental degradation. With examples from the global greenhouse effect, Amazonian deforestation and upland degradation on Java, Barbier develops a major theoretical advance and shows how it can be applied. This book breaks new ground in the search for an economics of sustainable development.

David W. Pearce, Anil Markandya and Edward B. Barbier
**Blueprint for a Green Economy**, Earthscan, London, 1989 (paperback £8.95)

This book was initially prepared as a report to the Department of Environment, as part of the response by the government of the United Kingdom to the Brundtland Report, *Our Common Future*. The government stated that: '...the UK fully intends to continue building on this approach (environmental improvement) and further to develop policies consistent with the concept of sustainable development.' The book attempts to assist that process.

Edward B. Barbier, Joanne C. Burgess, Timothy M. Swanson and David W. Pearce
**Elephants, Economics and Ivory**, Earthscan, London, 1990 (paperback £10.95)

The dramatic decline in elephant numbers in most of Africa has been largely attributed to the illegal harvesting of ivory. The recent decision to ban all trade in ivory is intended to save the elephant. This book examines the ivory trade, its regulation and its implications for elephant management from an economic perspective. The authors' preferred option is for a very limited trade in ivory, designed to maintain the incentive for sustainable management in the southern African countries and to encourage other countries to follow suit.

Gordon R. Conway and Edward B. Barbier
**After the Green Revolution: Sustainable Agriculture for Development**, Earthscan Pub. Ltd., London, 1990 (paperback £10.95)

The Green Revolution has successfully improved agricultural productivity in many parts of the developing world. But these successes may be limited to specific favourable agro-ecological and economic conditions. This book discusses how more sustainable and equitable forms of agricultural development need to be promoted. The key is developing appropriate techniques and participatory approaches at the local level, advocating complementary policy reforms at the national level and working within the constraints imposed by the international economic system.

David W. Pearce, Edward B. Barbier and Anil Markandya
**Sustainable Development: Economics and Environment in the Third World**, London and Earthscan Pub. Ltd., London, 1990 (paperback £11.95)

The authors elaborate on the concept of sustainable development and illustrate how environmental economics can be applied to the developing world. Beginning with an overview of the concept of sustainable development, the authors indicate its implications for discounting and economic appraisal. Case studies on natural resource economics and management issues are drawn from Indonesia, Sudan, Botswana, Nepal and the Amazon.

David W. Pearce, Edward B. Barbier, Anil Markandya, Scott Barrett, R. Kerry Turner and Timothy M. Swanson
**Blueprint 2: Greening the World Economy**, Earthscan Pub. Ltd., London, 1991 (paperback £8.95)

Following the success of *Blueprint for a Green Economy*, LEEC has turned its attention to global environmental threats. The book reviews the role of economics in analyzing global resources such as climate, ozone and biodiversity, and considers economic policy options to address such problems as global climate change, ozone depletion and tropical deforestation.

E.B. Barbier and T.M Swanson (eds.)
**Economics for the Wilds: Wildlife Wildlands, Diversity and Development**, Earthscan Pub. Ltd., London, 1992 (paperback £12.95).

This collection of essays addresses the key issues of the economic role of natural habitat and wildlife utilization in development. The book argues that this role is significant, and composes such benefits as wildlife and wildland products, ecotourism, community-based wildlife development, environmental services and the conservation of biodiversity.

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