# THE ECONOMICS OF SOIL EROSION: A MODEL OF FARM DECISION-MAKING

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# ABSTRACT

Soil erosion is widely considered to be a serious threat to the long-term viability of agriculture in many parts of the world. The problem is particularly serious in certain developing countries. This paper examines key factors affecting smallholder farmers, decisions about soil depletion and conservation. The analysis focuses exclusively on the on-site productivity losses due to soil erosion in an attempt to understand farmer behaviour, thus ignoring any externality effects or off-site costs.

The physical processes of soil erosion are described and its economic effects are reviewed, drawing on theoretical and empirical studies to date. Contrary to arguments that farmers are not aware of the extent and effects of erosion, an economic rationale for them to deplete their soil may be found in relatively simple conceptual models. While much of the research focuses on the North American context, this paper emphasises the relevance of economic models for analysing the situation in developing countries.

A simulation model is presented and used to describe the economic consequences of soil erosion for smallholder agriculture in Malawi. Simulation analysis indicates that few conservation measures will be attractive to smallholder farmers due primarily to the low productivity of this sector. The results highlight how incentives to invest in alternative cropping systems are influenced by a number of factors, including the initial and ongoing costs, the sensitivity of yields to erosion and the farmer’s discount rate. The study also compares alternative measures of the benefit of different cropping systems to the farmer and explores the implications of the results for agricultural pricing policy.

# 1. INTRODUCTION

Soil erosion is widely considered to be a serious threat to the long-term viability of agriculture in many parts of the world (*eg*, El-Swaify *et al.*, 1985). This concern is not without precedent. Human history contains many examples of previous civilisations whose downfall was caused at least in part by excessive soil erosion and the deterioration of the agricultural base (Lal, 1990; Hudson 1971). The problem is particularly serious in certain developing countries, where the importation of food to substitute for declining domestic production due to soil erosion, and the growing scarcity of arable land may be severely constrained by low foreign exchange earnings and high external debt burdens. In other cases, agricultural products may themselves constitute a country's main source of foreign exchange. Declines in agricultural productivity resulting from soil erosion would therefore hinder such a country's economic development, particularly in the absence of other export opportunities. In addition, many countries can anticipate continued expansion of agricultural production, for either domestic consumption or export, due to rapidly expanding populations.

Given that rapid rates of soil loss are occurring on farms in many parts of the world, a logical place to begin to look at the issue from an economic perspective is at the farm level. This paper examines the considerations taken into account by smallholder farms in making decisions about soil depletion and conservation. The analysis focuses exclusively on the on-site productivity losses due to soil erosion in an attempt to understand farmer behaviour. This does not imply however that off-site effects are negligible.

The paper consists of seven sections including the introduction, appendices and bibliography. The second section briefly describes some of the important physical relationships which must be understood in order to analyse the issue of soil erosion. The third section reviews the economic effects of soil erosion and the main theoretical and empirical studies to date. Within the agricultural economics literature and, to some extent, the natural resource economics literature, there is a strong interest in the issue of farmer decision-making and soil erosion. While some argue that farmers are often unaware of the extent and effects of erosion, an economic rationale for them to deplete soil resources may be found in relatively simple conceptual models. Much of this work focuses, however on the North American context. This paper emphasises the relevance of economic models for analysing the situation in developing countries.

The fourth section comprises a simulation study of the economic consequences of soil erosion for smallholder agriculture in Malawi. The first part of the simulation study defines and attempts to measure the Economic Productive Life of the Soil. The second part analyses the attractiveness to farmers of an alternative soil conserving cropping system. The main conclusion of the analysis is that few conservation measures are likely to be attractive to the smallholder farmer due primarily to the already low productivity of this sector. However the results are primarily tentative in nature while attempting to identify critical areas for further investigation. The simulation study also compares alternative measures of the attractiveness of different cropping systems to the farmer.

# 2. SOIL EROSION ON AGRICULTURAL LAND: PHYSICAL PROCESSES AND ECONOMIC EFFECTS

## 2.1 Physical Processes of Land Degradation in Relation to Agriculture

Lal (1990) points out that confusion often arises over the relationship between the terms soil erosion, soil depletion and soil or land degradation. *Soil erosion* refers to a loss in soil productivity due to:

> "physical loss of topsoil, reduction in rooting depth, removal of plant nutrients, and loss of water. Soil erosion is a quick process. In contrast, *soil depletion* means loss or decline of soil fertility due to crop removal or removal of nutrients by... water passing through the soil profile. The soil depletion process is less drastic and can be easily remedied through cultural practices and by adding appropriate soil amendments." (Lal, 1990, p. 9)

Erosion requires an agent, either wind or water. The level of erosion in a given place is determined by the interaction of a number of factors including climatic erosivity, soil erodibility and land use/management.[1] *Soil degradation* is a broader term for a decline in soil quality encompassing the deterioration in physical, chemical and biological attributes of the soil. Soil degradation is a long term process which may be enhanced by, among other things, accelerated soil erosion. Society is concerned about soil erosion primarily because of its contribution to longer term soil degradation, which is often irreversible. Attention focuses on soil erosion because it is a visible and measurable process and because it can be dramatically increased by human actions. In contrast, soil degradation consists of many interrelated processes and defies easy quantification (Lal, 1990, pp. 9-10).

Soil erosion occurs in both temperate and tropical regions. Climatic erosivity can be more acute in many tropical areas, particularly where rainfall is concentrated in fewer, more intense events. Soils in the tropics are often highly erodible, given their relatively shallow depth and low structural stability. While certain tropical soils are not particularly erodible in the absence of human interference, they can still be very susceptible to dramatic fertility decline (Hudson, 1971). Indeed, the consequences of soil erosion are often more severe in the tropics than in temperate regions because of the greatly inferior fertility of the subsoil (Lal, 1990, p. 17).

As climatic erosivity and soil erodibility are essentially given, land use and management practices are the deciding factor in determining the extent of soil erosion and erosion-induced degradation. On a given plot of agricultural land, erosion can vary from acute to almost nil depending on the cropping system. Vegetative cover plays a crucial role as erosion is significantly reduced under thick cover. In some cases a vicious cycle can arise, where erosion reduces soil productivity, resulting in less crop cover and hence more erosion and so on (Hudson, 1971). This "self-reinforcing feedback" highlights the problems facing poorer smallholder farmers in developing countries. Due to this sector's

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[1] Basic texts on soil erosion include Hudson (1971) and Morgan (1979). Lal (1990) provides a comprehensive review of erosion in the tropics.

lack of access to external resources, productivity on agricultural land is already low. In other words, generally poor crop cover means that poorer farms may suffer from more severe erosion on their land, resulting in less future production and even more erosion.

Lal (1990, p. 19) suggests that Africa may face greater problems of soil erosion than other regions. Although many parts of Africa do not yet face a situation of land scarcity, erosion-induced land degradation leads to the cultivation of ever steeper and more marginal land. This land is less productive and more susceptible to erosion, particularly when farmers transfer cultivation techniques better suited to land of higher productivity.

The effects of soil erosion may be divided into two categories: on-site and off-site effects. On-site effects consist essentially of reduced future agricultural productivity. Off-site effects arise from the transport of soil sediment and run-off to another location, such as another farm or a waterway. While the off-site costs can be quite substantial (*eg*, Crosson, 1983; Southgate *et al.*, 1984), this paper concentrates on the on-site productivity effects of soil erosion.

A reduction of agricultural productivity due to soil erosion is not necessarily problematic from an economic perspective. However, there are a number of reasons why erosion-induced productivity losses might be excessive from a *social* viewpoint in developing countries (Bishop 1992, and Bojö 1991). These include both the lack of markets and the presence of market imperfections and distortions. Capital market imperfections and the lack of risk and futures markets often imply that individual farmers will display a higher rate of discount than society. Bishop (1992) also points out that the lack of well-defined property rights over land may lead to an increase in the rate at which farmers discount future returns to conservation activities. In effect, farmers may be less willing to invest in conservation efforts if they are uncertain of reaping the future benefits.

Policy distortions are another major factor leading farmers to accept a rate of soil erosion higher than desired. Economists frequently appeal to the notion of a “social optimum” to describe a situation where all market imperfections and policy distortions have been removed, along with any bias reflecting short term private motivations (Bishop, 1992; Bojö, 1991). For instance, prices for agricultural inputs and outputs in developing countries are often set or regulated by government agencies. These may distort farmers’ incentives to conserve soil (Barbier and Burgess, 1992b). Other government interventions, such as exchange rate manipulations, can also lead to biases in relative prices. Lastly, imperfections in the markets for agricultural inputs and outputs can cause prices to diverge from their efficient levels, affecting the incentive to conserve soil.

Even if erosion-induced productivity losses are not excessive from a social point of view, off-site effects are likely to be excessive since these consist of external costs borne by others downstream. Whether the on-site or the off-site costs are judged to be excessive, there is a need to understand farmers’ behaviour with regards to soil erosion or conservation. Any intervention to correct either an externality or biased incentives must take into account farmers’ own perceptions if such an intervention is to have the desired effect (Barbier and Bishop, 1992). In most cases farmers will take into account only the on-site productivity losses due to erosion.

## 2.2 The Relationship between Soil Erosion and Agricultural Productivity

The relationship between soil erosion and agricultural productivity is complex and involves many different factors. By altering soil properties, erosion has direct effects on crop production. Erosion can decrease rooting depth, soil fertility, organic matter in the soil and plant-available water reserves (Lal 1987, pp. 313-4). Thus, the exposed soil remaining will be less productive in a physical sense. These effects may be cumulative and not observed for a long period of time. Erosion may also affect yields by influencing not only the soil's properties but also the micro-climate, as well as the interaction between these two (Lal 1987, p. 310).

While the negative effects of erosion on productivity are well documented, it is their magnitude which is of interest from an economic point of view.[2] Unfortunately, quantifying the effects of erosion on crop production presents many difficulties. First of all, the extent to which erosion affects crop production will vary depending on the type of crop, the type of soil, the micro-climate, local topography and the management system (Lal, 1987, p.310). Thus, the extent to which quantification of the relationship can be transferred between sites may be very limited. Secondly, even supposing that collecting vast quantities of location-specific data presented no problems, it is still extremely difficult to determine the influence of any *single* factor on crop yields (p. 308). Any attempt to measure the effect of erosion on yields will be almost impossible to control for other effects, such as variations in precipitation. These difficulties are particularly acute when one considers that the time frame involved (typically at least a few growing seasons) can result in many such uncontrollable variations. Long-term data is essential however, since the effects of erosion on productivity will change throughout the soil profile (Stocking 1984). In addition, the interaction among the various factors affecting crop production are only poorly understood.

Despite these difficulties, various attempts have been made to measure the erosion-productivity relationship. These have been reviewed by Stocking (1984) and more recently by Lal (1987). Much of this work has been done in temperate countries. Given that there tend to be significant differences (even in general terms) between not only temperate and tropical soils but also the crops grown on them, it is dangerous to generalise the research results of temperate areas (Lal 1987, p. 330). Stocking concludes that absolute yield declines due to erosion appear to be much greater in the tropics than in temperate regions. Moreover, initial yields in the tropics tend to be lower to begin with, meaning that declines will be even more serious (Stocking, 1984, p. 32).

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[2] It is sometimes suggested that soil that is deposited elsewhere through the process of erosion will increase crop production at the site of deposition, hence the loss of production in one place may be offset to a greater or lesser extent by an increase in productivity elsewhere (Crosson 1983). In particular, there may be less justification for being concerned about soil erosion if the eroded soil is deposited on the same farm from which it was eroded. However, there are other negative effects arising from soil deposition, such as crop burial, waterlogging and escaped water and nutrients. While even less is known about the deposition-productivity relationship, there is reason to believe that positive effects arising elsewhere will not fully offset the losses occurring at the point of erosion. It is not just the presence of soil which affects crop productivity but rather the soil's characteristics. These characteristics are radically altered in the process of erosion, transport and deposition. Moreover, even if the gains from deposition are significant, they often remain external to the accounting and decision-making framework of the farmer suffering erosion losses, hence an understanding of the farmer's behaviour in allowing the losses is still important.

Stocking (1984, p. 31) notes that the most intensive investigation of the effects of erosion on yield in sub-Saharan Africa was undertaken by Lal (1981; also reported in Lal, 1987, pp. 333-5) at the International Institute for Tropical Agriculture (IITA) in Ibadan, Nigeria during the 1970s. Over a ten-year period, Lal measured the rates of natural erosion and the yield of maize and cowpea grown on an alfisol on varying slopes (ranging up to 15%). Lal then estimated a regression equation with an exponential form relating cumulative erosion to yield:

$$Y = Ae^{-bx} \qquad \mathbf{1}$$

where $Y$ is yield in tonnes/ha, $A$ is a constant (equal to yield on un-eroded land), $e$ is the natural log, $x$ is cumulative soil loss (t/ha) and â is a constant that varies according to crop and slope. While different researchers have found somewhat different relationships between erosion and yields, there is growing evidence that, at least in the tropics, the decline in yields is of an exponential form (Blaikie and Brookfield, 1987, p. 17). This implies that initial declines are very high but fall as erosion proceeds.

Other researchers examining the economic effects of soil erosion have adopted the equation derived by Lal (Bishop and Allen, 1989; Bishop, 1990; Ehui *et al.*, 1990). It should be noted however that several caveats apply. Certainly the relationship is site-specific. In particular, it is based solely on alfisols. Transferring this equation to other sites is thus without much empirical justification. Another difficulty in applying the relationship to other areas is that one still needs some indication as to what the time profile of erosion is.[3] It is unlikely to be constant from year to year, as the characteristics of the exposed subsoil differ from the preceding topsoil. In addition, the relationship does not reflect in any way an upper limit to cumulative soil loss. Moreover, one does not know what happens to yields beyond this ten-year period. The yield-erosion relationship may not exhibit decreasing marginal losses over its whole range. There may be one or more inflection points. Another problem, especially pertinent to an economic analysis, is that these experiments do not give any indication of what the yield path over time would have been on identical or similar plots over the same period (*ie*, identical total precipitation and distribution) but where conservation measures (crop management) were taken to minimise soil erosion. A separate issue in transferring these results to other sites, particularly real farms, is that of the experiment controls for other inputs.

However, Lal’s result does have the advantage of being based on natural as opposed to simulated erosion, where top soil is removed mechanically. Lal (1981) found that yield declines due to natural erosion greatly exceed declines from comparable amounts of simulated erosion. The exponential relationship also has the attractive property of a constant proportional yield decline for a given amount of soil loss, regardless of the actual level of yield or cumulative erosion (Bishop and Allen, 1989). Hence

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[3] Measuring and predicting erosion rates presents formidable difficulties in its own right. Lal (1988) and El-Swaify *et al.* (1985) provide thorough reviews of the subject while Lal (1990) focuses on tropical applications.

$$Y_{t+1} = Y_t e^{-b \Delta x_t} \tag{2}$$

where $Y_{t+1}$ and $Y_t$ are the yields (in t/ha) in two adjacent time periods and Ä$x_t$ is the additional (or incremental) soil loss. One then only needs to know the level of soil loss and yield in one period to estimate the yield in the subsequent period. As this relationship appears to be the most robust available for any locality in sub-Saharan Africa, it may be used to illustrate various valuation methodologies which could be applied with greater confidence once further site-specific information is collected. In addition, one can use it for a range of â values to see what the situation *would* be like if the erosion-yield relationship were of a similar form (as done by Bishop and Allen, 1989; and Bishop 1990).

# 3. ECONOMIC ANALYSIS OF SOIL EROSION AND CONSERVATION

This section summarises the literature on economic analysis of soil erosion and conservation in the developing country context. It begins by reviewing the general theoretical advances, emphasising the importance of McConnell's seminal analysis (1983). This is followed by a review of how McConnell's model has been applied to analyse the effects of agricultural pricing policies on farm-level soil erosion in developing countries. Discussion then focuses on models emphasising the choice between alternative cropping systems, including empirical evidence. Unfortunately, studies estimating the costs and/or benefits of soil erosion and conservation in developing countries are scarce.

## 3.1 General Theoretical Development

Most economic analysis of soil erosion has been carried out in the US context, where the issue has received much public attention since the 1970s (Ervin and Ervin, 1982, p. 277). Recent work on the economics of soil erosion and conservation may be divided broadly into two strands: the first relies on empirical evidence to assess the whole range of factors influencing farmers either to conserve their soil or allow it to erode; the second strand employs formal modelling tools, such as optimization techniques, to identify the key trade-offs involved on decisions to adopt soil conserving practices.

Dating back to the late 1950s, and even the Dust Bowl (1930s) era, the literature in the first strand ascribes a key role to institutional factors, information and attitudes *(eg,* Ciriacy-Wantrup, 1952). Researchers emphasise the need to solicit farmers' perceptions and monitor their decisions. For example, Ervin and Ervin (1982) analysed cross-sectional data based on a survey of Missouri farmers and found that the likelihood of undertaking conservation measures was significantly correlated with the farmers' level of educational attachment and the degree to which they perceive erosion to be a major risk. The study also found that certain economic factors, in particular government farm subsidies, were also significantly correlated with erosion control effort while some others, such as farm income, were not.[4] More recently, Miranda (1992) has emphasised the importance of information and perceptions of the productivity effects of erosion. In a study of U.S. farmers enrolled in a government programme which paid them to remove highly erodible cropland from production, Miranda found that many farmers "did not understand or are failing to act on the on-site productivity effects caused by soil erosion". Such results underline a crucial information problem facing farmers; the costs and benefits of alternative cropping systems may not be known until they are tried.

In the 1970s the second strand of research, somewhat complementary to the first, gained increasing prominence. The appeal of more formal modelling, such as linear and dynamic programming techniques as well as the use of optimal control theory, was the ability, at least in theory, to separate farmers' decisions to adopt soil conservation from other unrelated decisions. (Seitz and Swanson, 1980, p. 1085). The major contribution of this approach has been to single out the impact of specific factors, such as prices and the discount rate, on the land husbandry decisions of a profit-maximising farmer.

In addition, such techniques clearly demonstrate the rationale behind a farmer's decision

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[4] Gould *et al.* (1989) report further testing of the Ervin and Ervin model.

to tolerate a certain amount of erosion. Some of the work is purely theoretical, and some formulates models for empirical application. Much of the research focuses on off-site costs or the impact of erosion on land prices. (As mentioned in the previous section, this paper does not dwell on the issue of off-site costs.[5]) The impact on land prices is of particular interest to economists examining soil erosion in the U.S. or anywhere else where private property rights and markets for agricultural land are fairly well-developed.

This paper concentrates on the results of one line of this second strand of research, which was initiated by McConnell (1983). His results are arguably the most influential in the theoretical literature and appear to be the only ones which have been applied in a developing country context. However, other approaches have been developed and their major results are reviewed briefly. Although in most cases the objective is the same – the maximisation of a stream of discounted returns from farming over time – the models vary in their choice of variables.

An early and influential model was developed by Burt (1981), who used a dynamic programming formulation with two state variables: depth of topsoil and the percentage of organic matter in the soil; and the percentage of land devoted to wheat as the control variable. The model was calibrated using data from the Palouse area of the northwestern U.S. Many other studies have been carried out in this region, which experiences significant rates of soil erosion and for which an extensive database exists (see, for example, Taylor *et al.*, 1986). Collins and Headley (1983) develop a model in which production declines due to soil erosion are depicted as a decaying income stream from a depreciating capital base. They find that “the optimal decay rate of income due to soil loss depends on current farm income, the interest [or discount] rate, and the cost effectiveness of soil conservation capital” (Collins and Headley, 1983, p. 70).[6] Clark and Furtan (1983) analyse soil conservation by portraying agricultural land as consisting of two components, a capital component comprising total nitrogen content and a fixed, “Ricardian” component essentially describing the micro-climate. The model, which is applied empirically to data from an area of Saskatchewan, Canada, achieves a greater level of detail and demonstrates the interaction between various factors influencing land productivity. But, aside from the significant data requirements, one also suspects that the most appropriate variables to represent the capital and Ricardian components would change in different contexts. These various approaches thus emphasise different aspects of soil erosion.

McConnell (1983) developed a simple model using optimal control theory in which soil depth and loss were incorporated into a single production function. In the tradition of natural resource economics, McConnell argues that soil is an asset which must compete with other assets. The return to the farmer obtained from soil is characterised by two elements. The first comprises the value of soil as an input to agricultural production in both the current and future periods, which thus contributes to profits. Secondly, the amount and productivity of the soil at the end of the planning period will affect the potential resale value of the farmer’s land, reflecting a capital element. One objective of McConnell’s model was to explain under what circumstances it can be optimal for a

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[5] Shortle and Miranowski (1987) is a good starting point for examining this literature.

[6] This model could be usefully combined with Lal’s (1987) productivity-erosion relationship (since the latter also has an exponential “decay” form).

profit-maximising farmer to tolerate soil erosion. The first order conditions yield the normal profit-maximising result: the farmer should use soil up to the point at which the value of its marginal product equals its marginal cost. The value is simply the additional current profit while the cost is the foregone future profits from depleting the soil in the current period plus the capital loss at the end of the planning period.

McConnell's model thus generates results familiar from other natural resource management problems and helps us to understand the intertemporal trade-off which farmers make (explicitly or implicitly) in their decisions regarding soil erosion. It follows from the first order conditions that any change which would increase the costs of soil loss or decrease the benefits would lead to a reduction in soil loss, and vice-versa. Hence a decrease in the farmer's discount rate or an increase in future prices, for example, will reduce the optimal rate of soil loss. Similarly, a temporary increase in current prices or an increase in the discount rate will result in greater soil loss.

McConnell argues that on-site productivity losses are unlikely to be excessive given two assumptions. The first is that the social objective function in agriculture (ignoring externalities) is identical to the individual farmer's objective function. This implies that the value of the farm to society is simply the rent it earns (pp. 87-8). The second assumption is that the social and private rates of discount are identical. Given these assumptions, the optimal path of soil loss from the perspective of an individual farmer will converge with that of society. As argued above, however, because of market imperfections and even the nonexistence of some markets, there are good reasons to expect that social rates of discount will not equal private rates in most developing countries. Hence, McConnell's conclusion may not be applicable in the latter context.

McConnell's model is often taken as a starting point in efforts to analyse farmers' decisions in developing countries.[7] Barbier (1988, 1990a) extends McConnell's model to reflect farmers' decisions on how much to invest in soil conservation measures. This is achieved by specifying an additional input package representing soil conservation measures. Such measures reduce the rate of soil loss due to production (assuming a single crop production function). Again the first order conditions yield intuitive results: farmers will invest in soil conservation up to the point that the marginal costs of doing so equal the marginal benefits. The latter consist of the discounted infinite stream of future production increases due to lower soil erosion. Comparative statics exercises (Barbier, 1990a, pp. 208-10) reveal that an increase in the discount rate creates an incentive to allow greater soil erosion. However, changes in the cost of inputs and the price of the agricultural output are more difficult to analyse (see below).

Much of the published criticism of McConnell's model (*eg*, Kiker and Lynne, 1986) focuses on the limitations of formal models for describing complex phenomena. While this is a valid reproach, McConnell's paper remains important, firstly, for describing how factors such as the discount rate will affect farmer behaviour, and secondly, for providing direction for future research.

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[7] The issue of resale value (capital gains/losses), is typically removed from the maximisation problem when McConnell's model is applied to developing countries, due to the general lack or presumed inefficiency of private markets in agricultural land. This is compensated, however, by extending the planning horizon towards infinity (see for example Barbier (1988, 1990a, 1991 and Barrett, 1989).

## 3.2 Agricultural Pricing Policies and Soil Erosion

Government intervention in agricultural markets can have significant impacts on farm-level incentives for soil conservation, as pointed out by Barrett (1989). Repetto (1988) argues that government regulations which artificially suppress producer prices create a disincentive to invest in land husbandry. Lipton on the other hand, argues the opposite case (cited in Barrett 1989). Barbier and Burgess (1992b) suggest that prices affect farmers' decisions regarding land husbandry in four ways: the level of agricultural production; incentives to invest in future production; changes in crop mixes through relative price changes; and effects on price variability *(ie,* to what extent farmers can reliably predict future prices).

Attempts to predict the direction of the effect (*ie,* positive or negative) of a change in either input or output prices on the aggregate level of current and future production, and hence soil erosion, highlight the dynamic nature of the soil conservation problem. Using a simple variant of McConnell's model, Barbier (1988a, pp. 209-10) shows that the impact of a price change cannot be generalised because of its contradictory effects. While an increase in the output price creates an incentive for increased soil erosion in the current period (to increase production and profits – Lipton's argument), the price increase if it is permanent, also increases returns to future production and thus creates an incentive to conserve more soil for future use (Repetto's argument). More formally, by increasing the profitability of agriculture, a price increase will lead farmers to use more inputs and increase agricultural output through either intensification or cultivating more land. Using more non-conservation inputs will tend to increase the rate of erosion, assuming that production increases can only be achieved in the short term at the expense of increased erosion. But the increase in profitability will also create an incentive to conserve the soil as an agricultural "input", implying greater soil depth and less erosion. The net effect on soil depth will depend on the relative size of these two influences, but one can easily imagine that they might cancel each other out. Barbier (1988a, p. 209) argues that for soils of poor quality or for those which are already highly degraded, the marginal loss of soil from increasing cultivation is likely to be high, while the marginal productivity of the soil is likely to be low. Hence one might expect a price rise to result in accelerated erosion.

Barrett (1989) uses McConnell's model to demonstrate that if changes in output and input prices due to some policy reform result in little or no change in the ratio of these prices, then the corresponding effect on land degradation may be minimal or even zero. This result, although apparently straightforward, has implications for developing countries in which producer prices are low and fertilizer use is subsidised. Liberalising both prices may leave the ratio between the two relatively unchanged. The conclusion drawn by Barrett is that the effects of price changes on land husbandry practices are difficult to predict but probably negligible.

However, Barrett's results should be regarded as only preliminary. A major feature of the model is that in the short-run production can only be increased by raising the rate of soil loss. This is a somewhat restrictive assumption which was used by McConnell (1983) in his original model. He provides the example that output could be increased by "cultivating land with greater slope, increasing soil loss" (p. 84). His intention appears to be to limit output increases "in a given time period" to those resulting in increased erosion. This is the familiar "current gains at future cost" argument and has some intuitive appeal. But it seems to be overly restrictive. Soil scientists and agronomists have demonstrated that even in the short-run (or one period), increased production can be associated with decreased soil erosion. For example, Hudson (1971) reports of an experiment which demonstrated on a low fertility soil in Zimbabwe that the application of fertiliser resulted in dramatically higher maize yields and lower soil erosion as compared to a case in which fertilisers were not applied. This results from the positive effect that increased ground cover due to increased production has on reducing the kinetic energy of rainfall and hence its erosivity.

The converse of the "current gains at future cost" argument is that future production cannot be increased without current losses. This argument reflects the nature of conservation investments which require substantial upfront costs as a price to pay for future improvements. However, the models used by McConnell and Barrett ignore the fact that soil conservation is most often undertaken in conjunction with a shift to an alternative cropping system. Thus the technical relationship between inputs and outputs will change *ie,* the production function will change. Hence while these models can be used to examine short-run trade-offs they miss essential features of the problem in the long run. They are also ill-suited to analysis of "steady state" situations where farmers choose between alternative cropping systems. (The next section examines models that look more explicitly at this choice.) In addition, as Barbier and Burgess (1992b) point out, the relationship between prices and output in developing countries is still poorly understood, let alone the connection with land degradation.

The discussion up to this point has focused decisions regarding a single crop. Farmers usually have a choice of which crops to grow. As noted by Barbier and Burgess (1992b; see above), changes in agricultural prices will affect land degradation indirectly by altering the mix of crops grown by farmers. Certain crops can be characterised as leading to more soil erosion under conventional methods of cultivation than others (Barbier, 1991; Barrett, 1989). Barbier (1991) extended his previous model to reflect the difference in the relative erosivity of different crops. The model predicts that changes in the relative prices (or output-input price ratios) of crops will encourage farmers to switch among crops. For example, an increase in the output price of a more erosive crop, such as maize, relative to the price of a somewhat less erosive crop, such as cowpea, could lead to increased maize cultivation and thus increased soil erosion. Barbier (1991) examines cropping patterns in Malawi over the period 1969-1988 to see if there is any correlation with observed shifts in relative gross margins. The evidence is sparse but does support the hypothesis that farmers may have increased their cultivation of pulses and groundnuts throughout the 1980s, as the returns to these crops increased relative to the returns obtained from more erosive crops such as maize and tobacco.[8]

Another way in which agricultural pricing policy can affect land management practices, as identified by Barbier and Burgess (1992b), is price variability. If relative prices and the returns from different cropping systems fluctuate significantly then one might expect farmers, particularly those in the smallholder sector, to be less likely to switch between systems given the high degree of risk involved. Barbier (1991) examined the variability of the non-erosive-to-erosive crop price ratio in Malawi over the same period and finds that farmers face a high degree of price risk "which could have an important influence on the

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[8] Note however that these shifts may have resulted from bringing more lands under cultivation as opposed to switching land from one crop to another (Barbier, 1991, pp. 23-4).

incentives for improved land management”.

### 3.3 Choice of Alternative Cropping Systems

The difficulty of formally describing farmers’ choice of alternative cropping systems has prompted some economists, particularly those undertaking empirical work, to adopt a more straightforward cost-benefit approach to analysing soil erosion and conservation decisions. Walker’s (1982) “damage function” essentially calculates the net incremental present value to the farmer of choosing an erosive cultivation practice in the current year as opposed to a more soil-conserving practice. His model is reproduced here with slight modifications and as applied in the Malawi simulation study presented in Section 4.

Walker defined the damage function, $\ddot{a}_t$ , as

$$d_t = p_e - p_c \qquad 3$$

where $\ddot{a}_t$ is the value of the damage function at time period t, $ð_c$ is the net present value of changing to the conservation practice in the current period and $ð_e$ is the net present value of continuing with the erosive practice for the current period and adopting the conservation practice in the subsequent period.[9] The latter terms are further expressed as follows:

$$p_e = P\,Y_e(t,D_{t-1}) - C_e(t,D_{t-1}) + \sum_{i=1}^{T-1} \frac{P\,Y_c(t+i,D_t) - C_c(t+i,D_t)}{(1+r)^i}$$

and 4

$$p_c = P\,Y_c(t, D_{t-1}) - C_c(t, D_{t-1}) + \sum_{i=1}^{T-1} \frac{P\,Y_c(t+i, D_{t-1}) - C_c(t+i, D_{t-1})}{(1+r)^i}$$

where $P$ is the price of the crop, $Y_e$ is the yield and $C_e$ the variable cost of the erosive practice. Both $Y$ and $C$ are functions of time and the depth of the soil in the previous period, $D_{t-i}$.[10] Similarly $Y_c$ and $C_c$ are respectively the yield and variable cost of cultivation of the conservation practice while $r$ is the discount rate. Substituting and rearranging terms yields equation (5).

$$\begin{aligned} d_t = {} & P\,[\,Y_e(t,D_{t-1}) - Y_c(t,D_{t-1})\,] \\ & - [\,C_e(t,D_{t-1}) - C_c(t,D_{t-1})\,] \qquad 5 \\ & - \sum_{i=1}^{T-1} \frac{P\,[\,Y_c(t+i,D_{t-1}) - Y_c(t+i,D_t)\,] + [\,C_c(t+i,D_t) - C_c(t+i,D_{t-1})\,]}{(1+r)^i} \end{aligned}$$

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[9] Note that the model assumes that farmers are already using the erosive practice.

[10] $D_t$ is defined as the depth of topsoil at the end of the current period *ie*, the amount of topsoil remaining for the next period.

An appealing feature of Walker's model is that the decision to adopt or defer soil-conserving practice is taken in each period. Thus if the farmer decides in the current period to continue with an erosive practice, the option is still open to adopt the conservation practice in the next period. With this assumption, it follows that the marginal user cost of continuing with the erosive practice is the loss in *future* revenue from delaying by one year the adoption of the conservation practice. This differs from other models (*eg*, Ehui *et al.*, 1990) where the loss would be calculated as the difference in future revenue between the erosive and conservation practice, assuming that each is continued throughout the entire planning period.[11] Walker defines the user cost as the amount that is *definitely* lost due to the current period. This may be thought of as the minimum amount that would be lost by delaying adoption of the conservation practice until at least next year. Walker (1982, p. 692) specifies the marginal user cost as the third term on the right-hand side (the summation expression) in (5) above. This term consists of two separate components. The first represents the lost future yields and the second represents the additional future costs of cultivation arising from the fact that the land is less productive.[12]

Little consensus exists however on how to define the user cost of soil erosion. The concept of user cost was originally defined by Keynes (1936), in the context of reproducible capital goods, as the change in value of such a good during an accounting period. Natural resource economists have extended the concept to describe changes in environmental and natural resource "capital" (El Serafy, 1989; Pearce and Markandya, 1989). The extension of the concept seems intuitive, although attempts define and measure user cost for certain resources raise both practical and conceptual difficulties.

Soil provides a good example to illustrate these difficulties. In agriculture, the primary economic function of soil is as a productive input.[13] However, the marginal productivity of soil can only be defined with reference to a particular cropping system. At first glance this cropping system may appear to be simply the technology factor in a production function. However, as seen above, one must decide which cropping system to use in calculating future production foregone as a result of choosing some practice today. Walker (1982) uses the conservation practice, an approach which resembles a best-available-technology method. Hence the losses will be less than if one presumed that the erosive practice chosen in the current period would be continued throughout the planning period. The latter approach has been used by other economists, particularly those examining developing country situations.

Magrath and Arens (1989) estimate the on-site costs of soil erosion in Java, Indonesia due to productivity losses. They argue that since erosion in Java is a recurring

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[11] *ie*, in the expression for ð$_e$ , the terms $Y_c$ and $C_c$ in the summation expression would be replaced by $Y_e$ and $C_e$ respectively.

[12] Walker (p. 692) describes this cost as being additional fertilizer required to maintain productivity. This is a common feature of models developed primarily with the U.S. context in mind, where some soil scientists argue that productivity declines due to soil erosion and land degradation are being masked by the increased application of chemical fertilizer.

[13] Ignoring for the purposes of discussion any other functions performed by the soil, in particular those which may be classified as externalities such as watershed protection, amenity value, etc.

phenomenon, the productivity losses should be treated as permanent (p. 32). This approach implies that yields will never rise above the level in the first year. Moreover, there is an implicit assumption that yields could have been maintained at their present level indefinitely.[14] Bishop and Allen (1989) and Bishop (1990) adopt a slightly different approach in their valuations of soil erosion induced productivity losses in Mali and Malawi. They assume that the loss in one period is sustained throughout the entire planning period. This point is not insignificant since the method of calculating the capitalised value of losses, or recurrent losses over time, can significantly affect the result. For example, capitalising the one year loss over an infinite time period with a ten percent discount rate (as was done by Magrath and Arens, 1989) results in a capitalised loss ten times greater than the one year loss (or almost 0.5% versus almost 0.05% of Indonesia's GDP).[15] Bishop's (1990) estimate of recurrent losses for Malawi exceed the one year loss more than eight-fold assuming a ten-year planning horizon and a 5% discount rate.[16]

It does seem appropriate to calculate the net present value to the farmer of alternative cropping systems if one wishes to analyse the issue of soil erosion from the farmer's perspective. Walker (1982), as noted above, has suggested allowing the decision of whether to shift to a more soil-conserving practice to be taken in each successive year. Another approach is to calculate the net present value (over a certain time horizon) of alternative systems, thus assuming that a choice of adopting a system occurs only at the beginning of the planning period.[17] This approach was adopted by Ehui *et al.* (1990) in analysing the returns to five different maize cropping systems in Nigeria. The cropping systems included two alternative alley cropping systems (*Leucaena* hedgerows planted at 2m or 4m intervals), continuous no-till and two traditional bush fallow systems (3-year cropping with 9-year fallowing and 3-year cropping with 3-year fallowing). Ehui *et al.* (1990) found that a 12-year crop fallow cycle was more attractive from the farmer's point of view than any of the conservation practices, but that the latter became more attractive as rising population density entailed higher opportunity cost of fallowing land.

Walker (1982, p.693) points out that the incentive to adopt the conservation practice should increase as erosion proceeds, since "yield damage with further soil loss increases at shallower topsoil depths". Indeed this is the relationship which Walker reports as having been estimated for the Palouse area. However, if yield is related to cumulative soil loss through an inverse exponential function, as in the equation estimated by Lal (1981) and noted in the previous section, then marginal production losses due to soil erosion *decline* as erosion proceeds.[18] In this case one would expect the incentive to adopt the

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[14] This common fallacy is highlighted by Fox and Dickson (1988) and Dickson and Fox (1989) in their reviews of attempts to calculate productivity losses due to erosion in Canada.

[15] Note also that the result is quite sensitive to the choice of the discount rate.

[16] The authors of all three studies appear to recognize the significance of these calculations and do explicitly acknowledge assumptions made.

[17] In contrast, the approach followed by Bishop and Allen (1989), Bishop (1990), and Magrath and Arens (1989) estimates the value of soil loss within *one* cropping system by deducting the lower revenues due to erosion from some higher level that could have been maintained hypothetically by the same cropping system (over a certain time horizon).

[18] Note again that the productivity-erosion relationship is not universal and neither is the functional form of the relationship. There is no reason to suppose that the rate of change in marginal productivity losses will be

conservation practice to decrease as erosion proceeds. This result is illustrated in the following section, through a case study of the Malawi smallholder sector. The simulation also attempts to compare the approach developed by Walker (1982) with the more conventional net present value calculations for some hypothetical conservation cropping systems.

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constant across different soils, crops, topography and climates.

# 4. MALAWI AS A CASE STUDY

In Malawi, the smallholder sector farms approximately 80% of arable land (with 45% of these households cultivating less than 1 ha) accounting for approximately 80% of food production and 90% of the population (Barbier and Burgess, 1992a).[19] The principal food crop is maize, comprising 75% of the cultivated area in the smallholder sector. Increasing land pressure, particularly in the South, has meant that many smallholder farms are reducing or foregoing fallow periods. This continuous cultivation is characterized by low yields, with the majority of farmers growing (indigenous/traditional) varieties of maize without fertiliser inputs, as well as high rates of soil erosion.

The economics of soil erosion and land degradation in Malawi has been the subject of various papers to date (Bishop, 1990; Barbier, 1991; Barbier and Burgess, 1992a). Bishop (1990) states that "the erosion of topsoil and the exhaustion of soil fertility under continuous cultivation are the most serious forms of resource degradation occurring on farm land in Malawi". Using data obtained from the government Land Husbandry Department, Bishop (1990) estimates the mean annual rate of soil loss on arable land at up to 20 t/ha. Combining this result with crop budgets from the Ministry of Agriculture and the erosion-yield relationship described in Section 2, Bishop estimates the on-site cost of soil erosion to be between 0.5% and 3.1% of 1988 GDP. As mentioned in the previous section, Barbier (1991) examines relative price variability for more erosive versus less erosive crops. Barbier and Burgess (1992a) provide a detailed review of the policy implications of land degradation in Malawi.

The purpose of this case study is to analyse some of the implications of declining yields due to soil erosion under continuous cultivation in the smallholder sector. The simulation is in two parts: the first attempts to determine the influence of various factors on the length of time that a typical smallholder farm will remain profitable with erosion-induced productivity declines. The second part uses data from several sources to determine the appeal to farms of an alternative, soil-conserving cropping system.

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[19] Unless specified otherwise, all statistics concerning agriculture in Malawi are taken from Barbier and Burgess (1992a).

## 4.1 The Economic Productive Life of the Soil

The simulation is carried out on a per hectare basis using the costs of smallholder production from the 1984/5 Agro-Economic Survey of the Ministry of Agriculture, as reported by Barbier and Burgess (1992a; Table 5).[20] These costs are reproduced in Table 1. The analysis consists of simulating a crop budget from season (one year) to season by applying the yield-erosion relationship – Equation (2). For simplicity, the analysis assumes that farmers, in response to the yield declines, will decrease their variable inputs in the same proportion (see Bishop 1990).[21] Thus gross margin (*GM*; equal to gross return less variable costs) may be substituted for yield in (2). The analysis is carried out under the alternative assumptions of labour as a fixed or variable input. A sample base case for soil loss of 20 t/ha/yr is illustrated in Figures 1 and 2 (and in Tables 1 and 2 of the Appendix) where it can be seen, for instance, that net income falls to zero after 7 years under the assumption that labour is a fixed input, or after 16 years assuming labour to be variable with â = 0.006. Following Bishop (1990), results are presented for a range of values for â (0.002 to 0.015).

The simulation equation for determining net income can be rearranged and solved for the number of years until the net income from the farm would reach zero under continuous cultivation. This may be written as

$$t^* = \frac{1}{b \Delta x} \ln \left[ \frac{GM}{FC} \right] - 1 \tag{6}$$

where the variables are as described previously and *FC* is fixed cost. $t^*$ is defined as the "economic productive life of the soil"[22] and is similar to Stocking and Pain's soil life concept (1983; as quoted in Stocking, 1984, p. 57) except that the former takes into account the economic environment of prices and costs in addition to the physical environment.[23]

Results of the simulation to determine the economic productive life of the soil are displayed for various parameters and crops in Tables 3 through 22 of the Appendix and summarised in Figures 3 to 6. One can see the crucial role played by both the level of annual erosion (which

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[20] The economic productive life of the farm is independent of farm size since the latter does not affect the rate of erosion under continuous cultivation.

[21] If farmers do not adjust variable inputs then net income declines even more rapidly.

[22] This should really be interpreted as the economic productive life of the *cropping system* since the time period is crop specific.

[23] However the *physical* basis of the soil life measure is more sophisticated than that of the economic productive life of the soil. The physical basis of the latter measure is the empirical erosion-yield relationship estimated in Nigeria using two crops (maize and cowpea) grown on an alfisol (Lal 1981). On the other hand, the soil life approach (developed in Zimbabwe) is a predictive model that links erosion and productivity through a knowledge of all of the following factors: erosion's effect on topsoil depth; soil texture and available water capacities; rooting depth for minimum water requirements; and crop tolerance to depletion of soil moisture (Stocking 1984). The increased physical sophistication comes therefore at the expense of much more detailed information needs. Ideally, one could extend the soil life measure with information on prices and costs. That was however beyond the scope of this paper.

## Table 1: Costs of Smallholder Crop Production in Malawi (1984/85)

| | **Local Maize** (with fertilizer) | **Local Maize** (without fertilizer) | **Composite Maize**[1] | **Hybrid Maize**[1] | **Groundnuts Chalimba** | **Groundnuts Manipinta** |
|---|---|---|---|---|---|---|
| Yield (kg/ha) | 850 | 1250 | 1800 | 3000 | 490 | 600 |
| Price (t/kg)[2] | 12.22 | 12.22 | 12.22 | 12.22 | 69.40 | 32.79 |
| Gross Return (Mk/ha) | 103.87 | 152.75 | 219.96 | 366.60 | 340.06 | 196.74 |
| **VARIABLE COSTS** (Mk/ha) | | | | | | |
| Seed | 3.06 | 3.06 | 12.50 | 25.00 | 63.00 | 31.50 |
| Fertilizer | | 48.70 | 43.90 | 82.90 | | |
| Labour | 33.50 | 33.50 | 48.30 | 64.11 | 73.01 | 73.01 |
| Transport | 10.18 | 16.58 | 22.84 | 38.10 | 6.66 | 8.01 |
| Credit | | 2.48 | 4.94 | 6.72 | 5.86 | 3.15 |
| **TOTAL** | 46.74 | 104.32 | 132.48 | 216.83 | 148.53 | 115.67 |
| **FIXED COSTS** (Mk/ha) | 8.39 | 8.39 | 8.39 | 8.39 | 8.39 | 8.39 |
| **TOTAL COSTS** (Mk/ha) | 55.13 | 112.71 | 140.87 | 225.22 | 156.92 | 124.06 |
| **NET INCOME** (Mk/ha)[3] | 48.74 | 40.04 | 79.09 | 141.38 | 183.14 | 72.68 |
| **GROSS MARGIN** (Mk/ha)[4] | | | | | | |
| Labour fixed | 90.63 | 81.93 | 135.78 | 213.88 | 264.54 | 154.08 |
| Labour variable | 57.13 | 48.43 | 87.48 | 149.77 | 191.53 | 81.07 |
| TOTAL STANDARD MAN DAYS (SMD)/ha | 52.35 | 52.35 | 75.48 | 100.18 | 114.08 | 114.08 |
| **NET INCOME/ SMD/ha** | 0.93 | 0.76 | 1.05 | 1.41 | 1.61 | 0.64 |
| **GROSS INCOME/ SMD/ha** | 1.73 | 1.57 | 1.80 | 2.14 | 2.32 | 1.35 |

**NOTES:**

1. Both hybrid and composite maize are grown with fertilizer
2. 1 t (tambala) = 0.01 Mk (Malawi kwacha); 1985 Exchange rate: 1 US$ = 1.68 Mk (IMF 1991)
3. Net income = Gross return - Total Costs
4. Gross Margin = Gross return - Total variable costs

**SOURCE:**

Adapted from Barbier and Burgess (1992a, Table 5); Original Source: Planning Division, Agro-Economic Survey - A Production Cost Survey of Smallholder Farmers in Malawi, Report No. 55, Ministry of Agriculture, Lilongwe, Malawi, April 1987

**Figures 1 and 2: Simulation of Net Income for Local Maize without Fertilizer**

**for Soil Loss = 20 t/ha/yr**

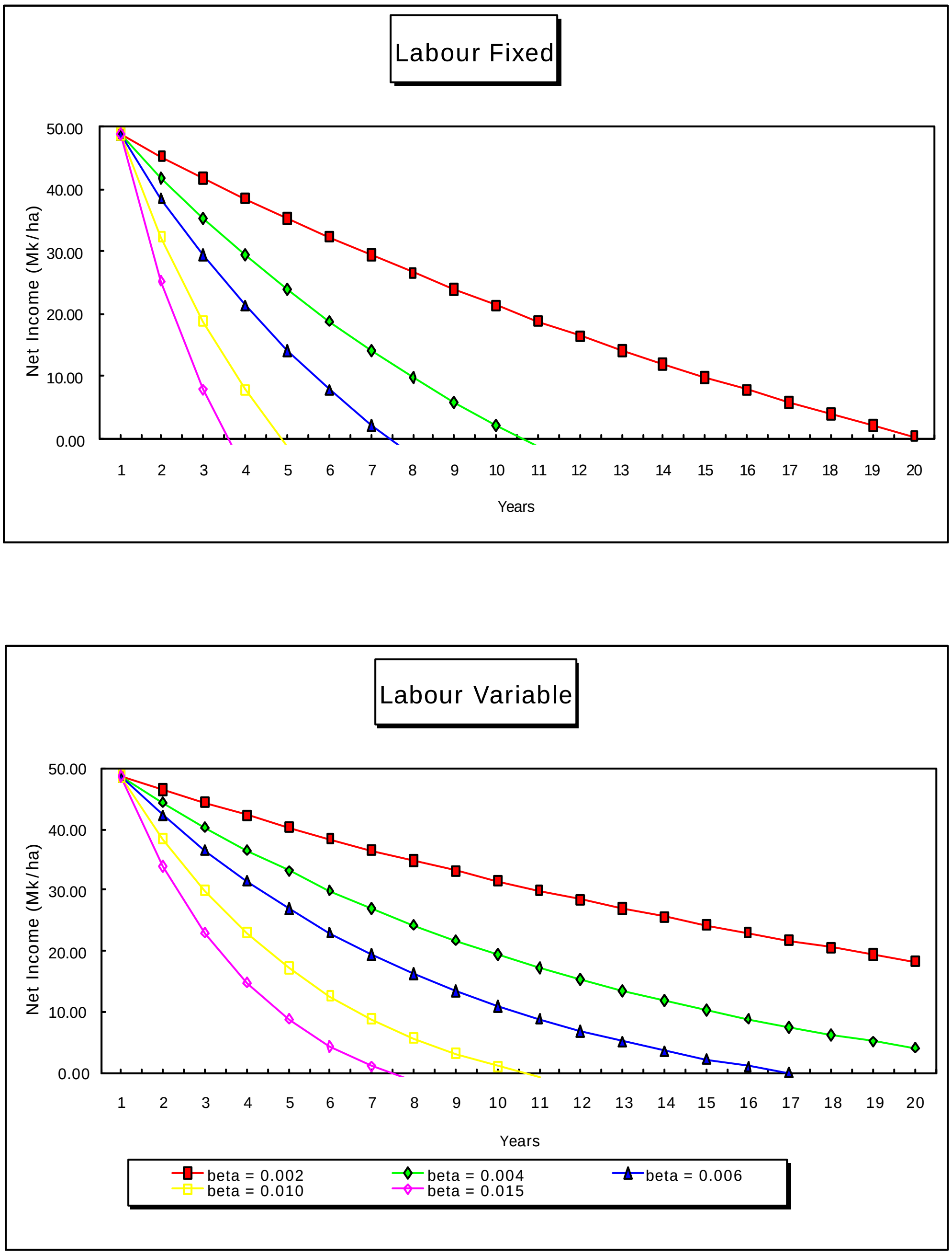
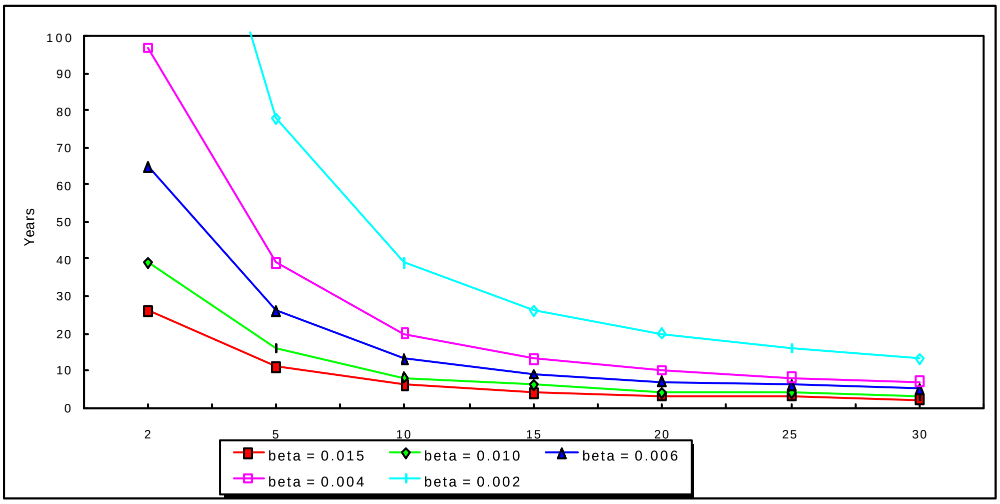
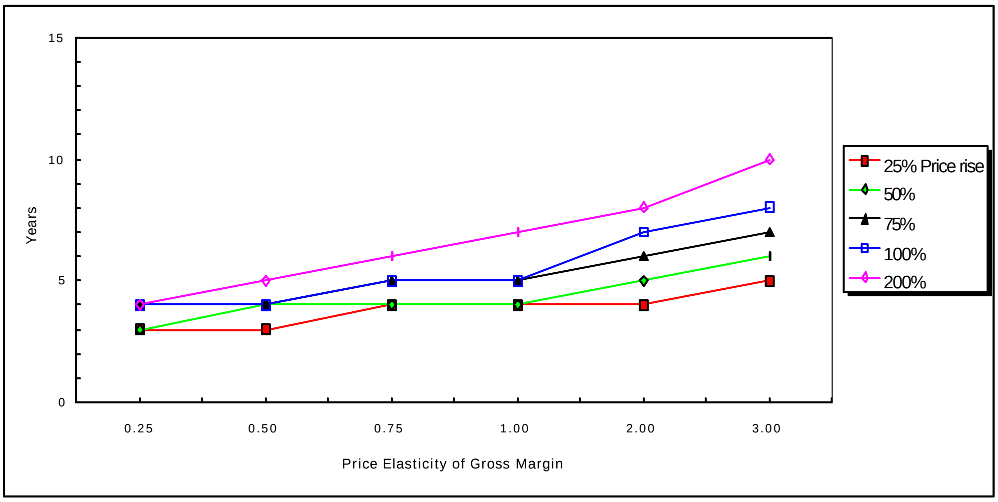


**Figure 3: Economic Productive Life of Soil - Local Maize No Fertilizer**
(Labour Fixed)



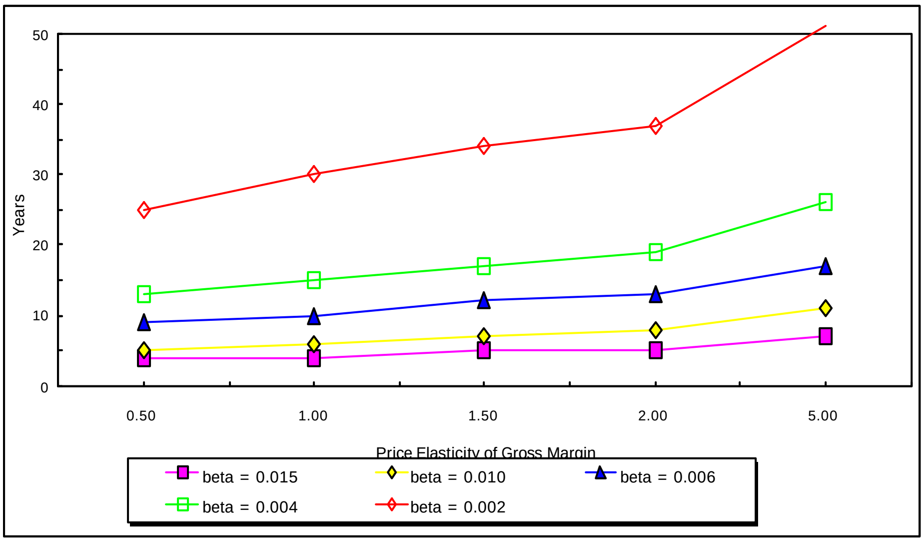
Source: Appendix, Table 3

**Figure 4: Economic Productive Life of Soil - Local Maize No Fertilizer for Various Output Price Rises with Various Elasticities of Gross Margins**
(Labour Fixed)



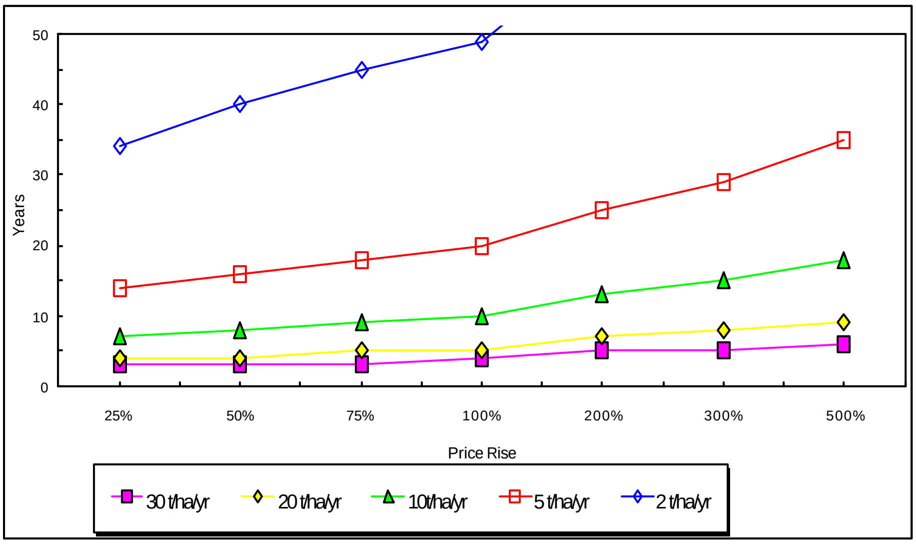
Source: Appendix 1, Table 8
Assumptions: Beta = 0.015
Soil Loss = 20 t/ha/yr

### Figure 5: Economic Productive Life of Soil - Local Maize no Fertilizer for 50% Output Price Rise with Various Elasticities of Gross Margins (Labour Fixed)



Source: Appendix 1, Table 4

### Figure 6: Economic Productive Life of Soil - Local Maize No Fertilizer for Various Output Price Rises and Rates of Soil Loss (Labour Fixed)



Source: Appendix 1, Table 17

Assumptions Beta = 0.015

Price Elasticity of Gross Margin = 1

would not usually remain constant) and the beta value (see Figure 3). This indicates that significant gains can be achieved by reducing erosion (disregarding costs for the moment) and follows from the exponential nature of the erosion-productivity relationship used. It also suggests that the economic productive life of the farm would be even lower if erosion accelerated over time as productivity declined. It should be emphasised that the actual values presented probably do not represent true values, due to the number of simplifying assumptions made. However, by conducting sensitivity analysis on numerous variables it is possible to illustrate which factors are most significant in determining the long run effects of soil erosion.

Another point illustrated by the data is that whether labour is regarded as a fixed or variable input significantly affects the economic productive life of the farm (regardless of the level of erosion or beta). When labour is a variable input to cultivation farmers are assumed to reduce their use of labour as soil productivity declines. Hence net income will not decline as rapidly, prolonging the economic productive life of the cropping system. Given that labour costs are the main factor in the production of unfertilised local maize this result is not too surprising. Thus future work on the economics of land husbandry in the smallholder sector should investigate how farmers adjust their labour input as productivity declines due to erosion.[24]

Real price changes may also affect the economic productive life of the cropping system, depending on how farmers respond to price changes. In a single crop context, one would expect farmers to react to a price increase by employing more variable inputs and producing more with an overall increase in the gross margin. The analysis here was undertaken with a range of assumptions to examine the effect on the economic productive life of the farm. To simplify matters a range for the elasticity of gross margins with respect to producer price is taken. Assuming the elasticity is 1, soil loss is 20 t/ha/yr and beta is 0.006, price rises ranging from 25% to 500% will change the economic productive life of the local maize without fertiliser cropping system from 7 years to 9 to 22 years. Varying the elasticity on a similar scale as the price change has similar effects on the economic productive life (see Figure 4 and Appendix Tables 7 to 10). This is because the two variables are multiplied by each other and range over similar values. For this reason the simulation shows that the level of the elasticity is important in determining the effect of the price change on the economic productive life. However, as illustrated by Figures 5 and 6 (see also Tables 7 to 10 of the Appendix), the level of beta (and hence also of soil loss) appears to have a greater effect on the economic productive life.

While at first glance these results may appear as evidence confirming Barrett's (1989) argument that price rises may not have a large influence on soil conservation, an important distinction should be made. Barrett's argument, as reviewed in Section 3, concerned whether price changes would affect farmer's willingness to undertake conservation measures. Analysing the effects of price changes on the economic productive life of the cropping system assumes that the cropping system remains fixed. So price increases are really just a way of keeping the farm profitable in this analysis. The effects of Barrett's argument on this data set are illustrated in the following section.

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[24] The response could go in either direction. The household might increase labour input in order to maintain production (to the extent that this is possible) or it might divert labour to more remunerative activities.

## 4.2 Alternative Cropping Systems

There are different ways of comparing the attractiveness to the farmer of alternative cropping systems as reviewed in Section 3. The most straightforward is to calculate the net present value of income under the alternative systems. Walker has proposed a somewhat different approach, known as the damage function. Another method is to compare the return to labour *ie,* the net incremental present value per unit of labour. This section combines the data set from Malawi with some analysis carried out by Ehui *et al.* (1990) for Nigeria, to assess the attractiveness of an alternative cropping system – no-till – to the Malawian smallholder farmer based on two measures, the present value of incremental net returns (PVINR; a net present value measure[25]) and Walker's damage function (delta). The analysis assumes that households produce a marketable surplus with all values for PVINR and delta reported on a per hectare basis. As in the previous section, the results should be seen as primarily illustrative.

To determine the potential costs and yield effects of the no-till cropping system, data from Ehui *et al.* (1990) was adapted (with some assumptions) for the Malawian smallholder sector. For the no-till analysis, labour costs were reduced by 35% as per Ehui *et al.* (1990; the result is originally from Ngambeki, 1985). The reduction results from lower weeding requirements arising from the increased use of herbicide.[26] As a reliable method for estimating herbicide costs could not be obtained, the analysis was carried out using a wide range of values of 10, 30 and 50 Mk/ha.[27] Initial yields for maize were calculated as 900 kg/ha, which exceeds the initial yield for the continuous case of 850 kg/ha by approximately the same percentage (6%) as used by Ehui *et al.* (1990, p. 356).[28] The analysis also includes the cost of a sprayer for the herbicide. Ehui *et al.* (1990, p. 357) estimated the purchase price at $76. Based on a 1985 exchange rate of 1.68 Mk/$, the price in Malawi would be 128 Mk. This represents a significant upfront cost for the no-till cropping system.[29]

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[25] PVINR is calculated by deducting the stream of net income that would be earned by maintaining the existing cropping system from the stream of net income from the proposed cropping system (over the planning horizon) and determining the present value of this "incremental" stream.

[26] It is possible that labour required for tilling will also be saved. Unlike Ehui *et al.* (1990), this analysis assumes that land has already been cleared given the higher population density in Malawi as compared to Nigeria. Hence no additions or allowances are made for land clearing costs.

[27] The mid-point of this range, 30 Mk/ha, was calculated by applying the ratio of herbicide to seed costs (equal to 10) from Ehui *et al.* (1990) to the seed costs from the Malawi crop budgets. This somewhat arbitrary procedure was followed because seeds were the only purchased input in the Malawian cropping system, and thus provided a reference point for relative input costs.

[28] Note that the traditional and no-till cropping systems were both far more productive in the Nigerian study, exceeding the yields of continuous cultivation in Malawi by 100%-200%.

[29] If the farm purchases the sprayer on credit then income will not drop as much in the first period but will rise more slowly over the rest of the planning horizon as the farm is required to pay off the loan. Evidence from Malawi indicates that credit, particularly medium-term credit required for purchasing major capital inputs, is often not available in the smallholder sector (Barbier and Burgess, 1992, pp. 5-8). Hence it may not be possible for farms to undertake no-till systems even when the PVINR or the damage function value indicate that it might be preferable.

The basic difference between the PVINR and delta measures is illustrated in Figures 7 and 8. Figure 7 shows that PVINR measures the difference in net income between investing in the no-till system and not investing at all – the area between the two lines. On the other hand, delta measures the difference in net income between investing in the no-till system this year as opposed to next year – the area between the two lines in Figure 8.[30] Each measure thus evaluates a different decision on the part of the farmer.

Results of the simulation are reported in Figure 9 and Table 2 for a 10 year planning horizon and using a 10% discount rate.[31] Figure 9 illustrates PVINR (plotted against the left-hand axis) and Walker's damage function (delta; plotted against the right-hand axis) for various levels of beta and herbicide cost assuming that the no-till system reduces soil erosion from 20 to 2 t/ha/yr. Recall from Section 3 that Walker's damage function (ä, or delta) measures the cost to the farmer of maintaining the continuous cultivation system for the current period. Hence negative values for delta imply that it is more attractive to switch to the no-till system while negative values for PVINR indicate that it is more attractive to choose the continuous cultivation system for the length of the planning horizon. To facilitate comparison with PVINR, delta is displayed with the *opposite* sign (*ie*, values are multiplied by -1). Hence positive values of delta in the graphs indicate greater returns to switching to the conservation practice in the initial period, as do positive values of PVINR.

Figure 9 illustrates that whether PVINR or delta favour the adoption of the no-till system depends on the sensitivity of yields to erosion and the cost of herbicide. When yields are less sensitive to erosion (low beta), PVINR indicates that it is more profitable for the farmer to remain with the continuous cultivation system, unless herbicide costs are minimal. On the other hand, delta is positive for low beta and even moderate herbicide costs, thus favouring the adoption of the no-till system in the current year. In general, as the costs of herbicide decrease and sensitivity of yields to erosion increases, delta is faster than PVINR to indicate that farmers should switch to the no-till system. This comparison underlines the importance of understanding the decision-making process at work.

If labour is assumed to be variable rather than fixed, then the no-till option is even more unattractive than continuing with the continuous cultivation, using either the PVINR or damage function measure. The rest of the analysis therefore treats labour as a fixed cost. Since farmers are in fact likely to adjust their labour inputs, the conclusion that this no-till alternative would appeal to farmers only under special circumstances is reinforced.

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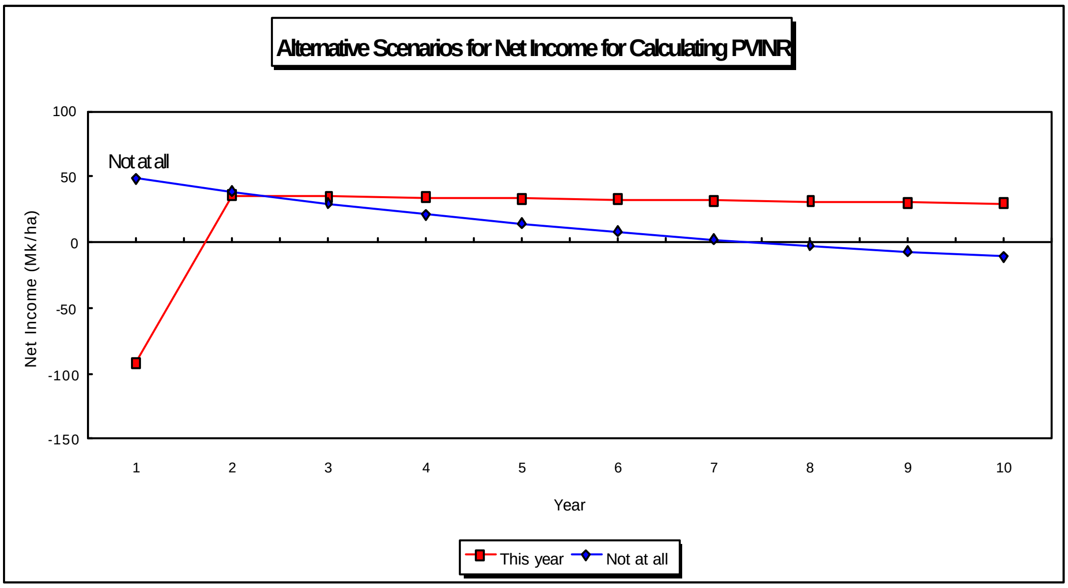
[30] For illustrative purposes, Figures 7 and 8 do not incorporate the availability of credit for purchasing the sprayer, which must be paid for entirely in the first period.

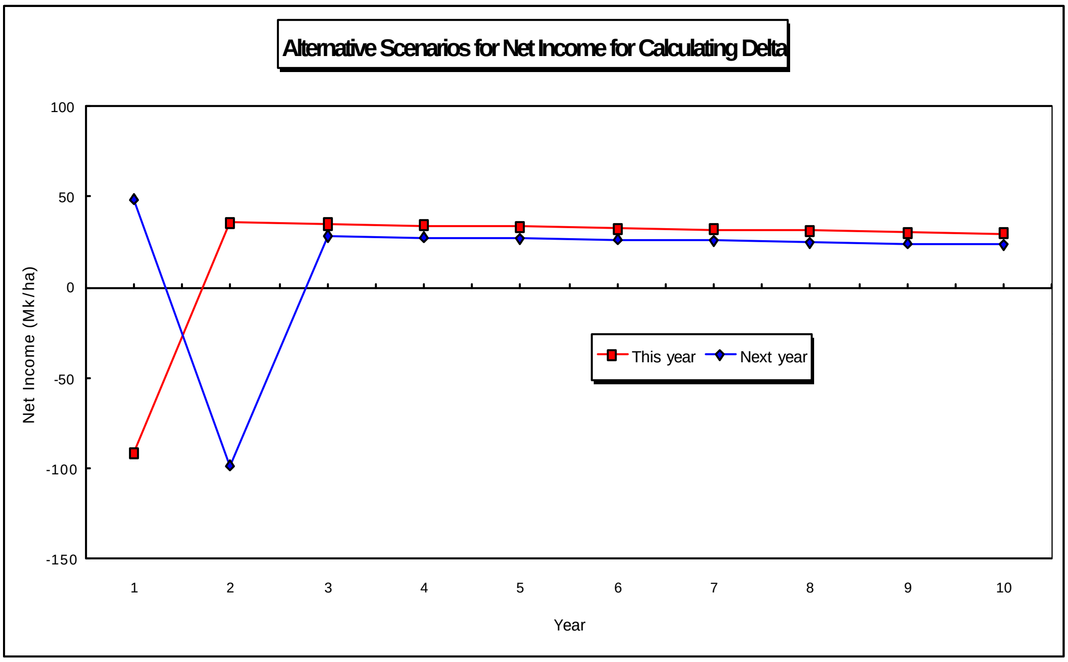
[31] PVINR and delta were also calculated for a 20 year planning horizon but the results are not reported since changing from a 10 to a 20 year horizon did not affect the outcome nearly as much as other variables, such as herbicide costs or discount rates. In general, a longer planning horizon leads to a modest improvement in the attraction of the no-till system, using either the PVINR or delta measure. This results from the fact that, with a longer planning horizon, additional periods of higher net income under the no-till system are taken into account (see Figures 7 and 8).

### Figure 7: Investing This Year vs. Not Investing at All



| Assumptions for Both Figures: | Beta = 0.006 | Soil Erosion Reduced from 20 to 2 t/ha/yr |
|---|---|---|
| | Herbicide Cost = 30 Mk/ha | Labour fixed |

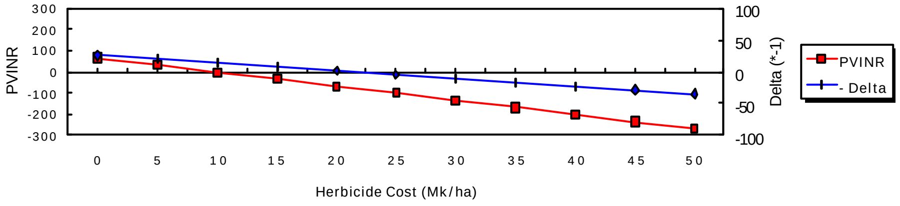
### Figure 8: Investing This Year vs. Investing Next Year



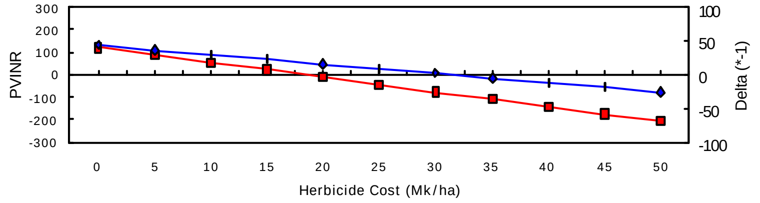
| Assumptions for Both Figures: | Beta = 0.006 | Soil Erosion Reduced from 20 to 2 t/ha/yr |
|---|---|---|
| | Herbicide Cost = 30 Mk/ha | Labour fixed |

**Figure 9: PVINR and Delta as a Function of Herbicide Costs for Various Beta's**

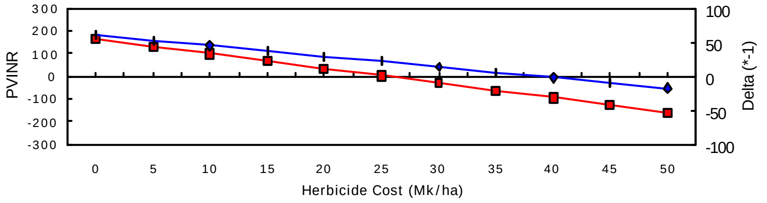
Beta = 0.002



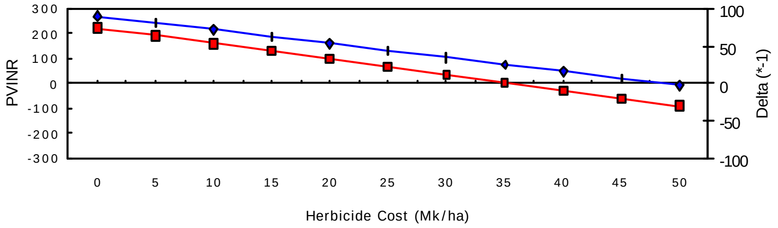
Beta = 0.004



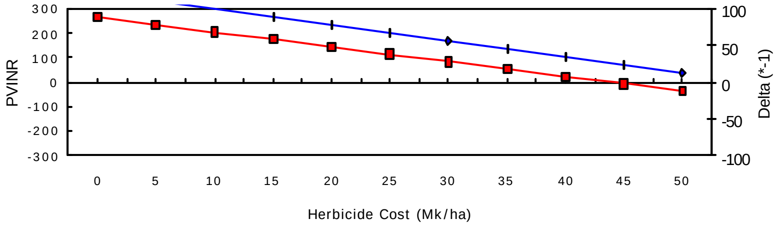
Beta = 0.006



Beta = 0.010



Beta = 0.015



Assumptions 10 year planning horizon
Discount rate = 10%
Labour fixed
Soil Loss reduced to 2 t/ha/yr with no-till

### Table 2: Calculation of PVINR and Walker's Damage Function
### No-till Cropping System for Different Costs of Herbicide

| | Beta | | | | |
|---|---|---|---|---|---|
| | 0.002 | 0.004 | 0.006 | 0.010 | 0.015 |
| **PVINR** | | | | | |
| Herbicide Cost | | | | | |
| 10 | (2.15) | 54.49 | 98.68 | 160.35 | 205.16 |
| 30 | (135.34) | (76.75) | (30.66) | 34.68 | 83.85 |
| 50 | (268.53) | (207.99) | (160.00) | (90.99) | (37.46) |
| **Walker's Damage Function (* -1)** | | | | | |
| Herbicide Cost | | | | | |
| 10 | 13.56 | 29.72 | 44.75 | 71.69 | 100.17 |
| 30 | (10.44) | 1.99 | 13.55 | 34.29 | 56.20 |
| 50 | (34.45) | (25.74) | (17.64) | (3.12) | 12.22 |
| **Bishop's Recurrent Loss** | 24.02 | 47.10 | 69.27 | 111.04 | 158.77 |

Assumptions:
10 year planning horizon
Discount rate = 10%
Labour fixed
Soil Loss reduced from 20 to 2 t/ha/yr with no-till

Figure 10: PVINR for Various Betas and Discount Rates

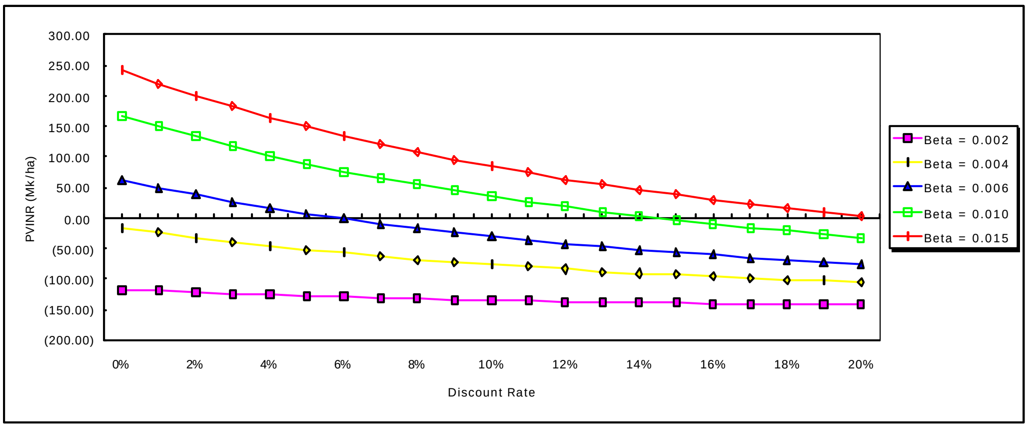
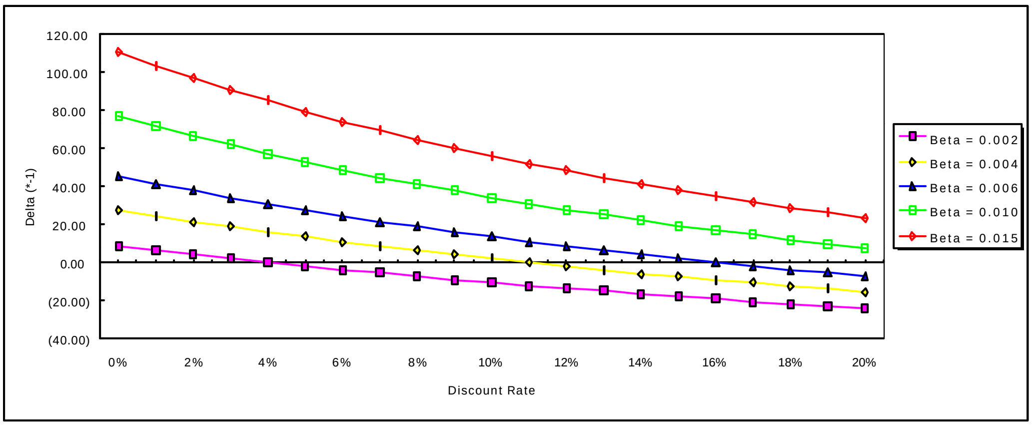


Figure 11: Delta (*-1) for Various Betas and Discount Rates



Assumptions for Figures 10 and 11:
10 year planning horizon
herbicide cost = 30 Mk/ha
Soil erosion reduced to 2 t/ha/yr
Labour fixed

> It is worth noting that the values for PVINR are typically greater in absolute terms than those for the damage function. This results from the fact that the former measures the attractiveness of switching to the no-till system for the duration of the *entire* planning horizon, while the damage function indicates the difference between the two systems based on only one period (but examining the effects over the entire planning horizon, the user cost). Thus the values for PVINR are quite substantial, greatly exceeding net income in a given year, while the damage function values tend to be more modest.

Table 2 also reports values for Bishop's "recurrent" loss calculation (the value of one year's productivity loss – per hectare – sustained over the planning horizon). These are based purely on the continuous cultivation system and show, as reported by Bishop (1990), quite substantial losses. In spite of these potential losses, the PVINR measures and the damage function estimates generally favour the maintenance of the continuous cultivation system (for the parameters specified in Table 2). This comparison demonstrates the importance of comparing alternative cropping systems, since some losses in future yields may not be avoidable regardless of the system employed.

Figures 10 and 11 show the results of PVINR and delta for various discount rates and beta values. The results illustrate the considerable effect of the discount rate on the appeal of investing in the no-till system to maintain higher yields in the future. For example, even assuming that the no-till system almost eliminates erosion (reduced from 20 to 2 t/ha/yr), PVINR becomes positive at lower discount rates only for higher values of beta. This suggests that in addition to the effectiveness of the no-till system in reducing erosion and the cost of additional inputs required, the attractiveness of such a system will be influenced significantly by the farmer's discount rate. Thus the appeal of the no-till system depends on both the purely technical attributes of the system as well as the behavioural characteristics of the farmer.

Given the importance of the effectiveness of the no-till system in reducing erosion, switching values for the annual soil loss under the no-till system were calculated for both PVINR and the damage function assuming various costs of herbicide and a 10% discount rate.[32] Figures 12 and 13 indicate that for low cost of herbicide, the no-till system need only achieve a modest improvement in the rate of soil loss for PVINR or delta to favour a switch. As herbicide costs increase, though, whether the no-till system can even appear attractive depends heavily on the sensitivity of yields to erosion (beta). For low beta (and thus low sensitivity of yields to erosion), higher herbicide costs quickly outweigh yield improvements, even if erosion is completely eliminated (as indicated in Figures 12 and 13 by the lines meeting the horizontal axis). Yet again, the results also illustrate how delta tends to favour early adoption of the no-till system more than does PVINR.

As can be seen from Figure 14, PVINR and delta (multiplied by -1) decline over time. This implies that the attraction of the no-till system decreases as erosion proceeds over time and the farmer continues with the existing, more erosive cropping system. This feature results

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[32] The switching value is the maximum level of soil erosion that must be achieved under the no-till system for that system to appear attractive according to PVINR or delta (assuming, as always, that the continuous cultivation system is initially experiencing erosion at a rate of 20 t/ha/yr). The switching value is thus calculated by setting either PVINR or delta to 0 and solving the simulation for the annual rate of soil loss (under the no-till system).

Figure 12: Switching Values for Soil Erosion to be Achieved under the No-till Cropping System for PVINR to favour the No-till System for Varying Costs of Herbicide

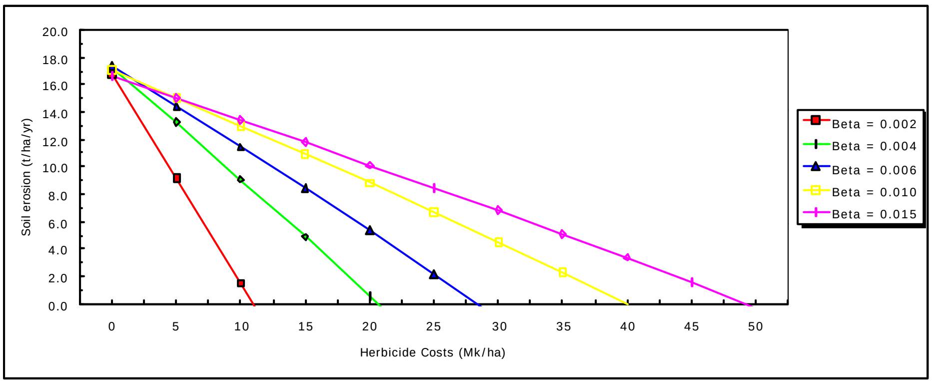
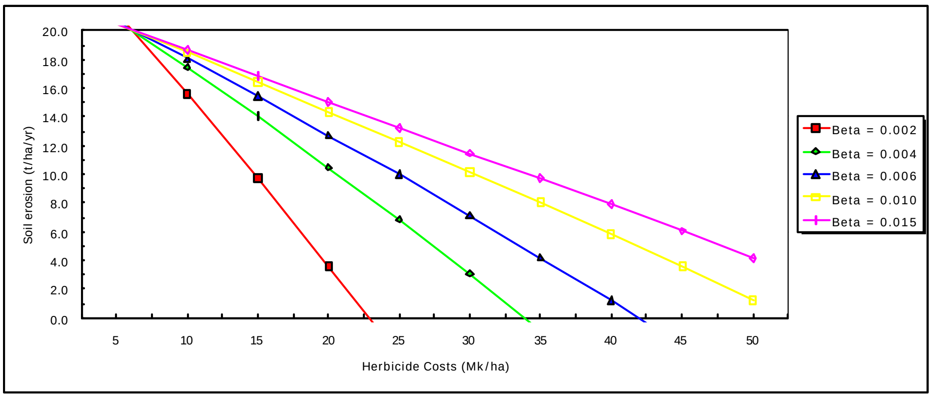
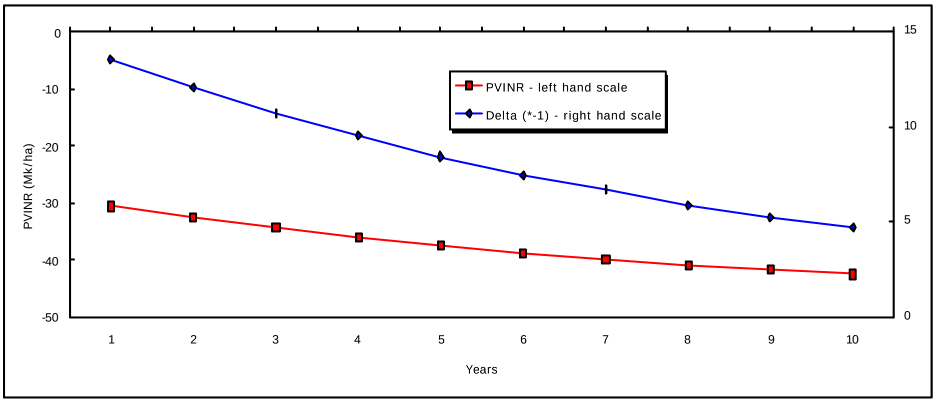


Figure 13: Switching Values for Soil Erosion to be Achieved under the No-till Cropping System for Delta to favour the No-till System for Varying Costs of Herbicide



| Assumptions for Figures 12 and 13: | Continuous cultivation system is initially experiencing erosion of 20 t/ha/yr<br>10 year planning horizon<br>Labour fixed<br>10% discount rate |
|---|---|

Figure 14: PVINR and Delta over time



| Assumptions: | Labour fixed<br>10 year planning horizon<br>10% discount rate | Beta = 0.006<br>Cost of herbicide = 30 Mk/ha<br>Soil erosion reduced from 20 to 2 t/ha/yr |
|---|---|---|

from the functional form for the erosion-productivity relationship (with increasing marginal productivity of soil) and the assumptions in the simulation that this relationship is stable over time (a ten-year period) as erosion proceeds. Again, as noted above, one would expect to see some changes in this relationship, particularly an accelerating (or abrupt) decline in productivity, as soil reaches critical levels.[33]

Figures 15 to 18 show changes in PVINR and delta (per hectare) for output price rises under various assumptions about the price elasticity of gross margins and the discount rate.[34] The results demonstrate the importance of both variables in determining the influence of a price rise on the attractiveness of adopting the no-till system.[35] At low to moderate discount rates, no-till's appeal increases with price increases because the no-till system involves both higher initial yields as well as higher future yields due to decreased erosion. However, Figures 17 and 18 show that, at a discount rate of 20%, output price rises have little effect on the appeal of the no-till system. Indeed, PVINR actually decreases with greater price rises (under base case assumptions). At such a high discount rate, the stream of future improvements in net income is given less consideration than the immediate drop in net income resulting from investment in the no-till system.

The results indicate that substantial producer price increases may dramatically increase the incentive for farmers with a low to moderate discount rate to adopt soil-conserving practices. This contrasts sharply with Barrett's theoretical results discussed in Section 3 and underscores the impact that price changes can have on the appeal of various cropping systems, thus confirming Barbier's result and the argument advanced in Section 3. The analysis therefore further suggests that soil conservation measures are best evaluated as alternative cropping systems, rather than as inputs to an existing system, or production function.

To be more realistic, an analysis of the attractiveness of alternative cropping systems should address the whole range of such possibilities. Alternatives include both other biological conservation measures, such as agroforestry systems, as well as mechanical measures, such as contour bands. Such alternatives are not evaluated here due to the lack of data but the analysis would be similar.[36] Most techniques require a greater amount of

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[33] For example, once the soil is completely eroded away, yields would obviously drop to zero. This highlights the fact that estimated relationships, such as Lal's (see Equation 1), are not intended to describe what happens at extremes.

[34] Recall that the simulation assumes that households are surplus-producing. Food deficit households may suffer as a result of output price rises and an analysis of the attractiveness of alternative cropping systems under such circumstances would have to be carried out independently.

[35] Both sets of figures were calculated using base case assumptions (beta = 0.006; cost of herbicide = 30 Mk/ha; soil erosion reduced from 20 to 2 t/ha/yr by adopting the no-till system; and a 10 year planning horizon) which result in delta favouring adoption of the no-till system and PVINR indicating that it is more profitable to remain with the continuous cultivation system. As in Figure 9, this dichotomy disappears as the assumptions move towards a combination of either low sensitivity of yields to erosion (low beta) and high herbicide cost, or the other way around.

[36] While mechanical systems have been widely promoted in the past, there is growing opinion among soil scientists that biological or agronomic measures, such as no-till and alley cropping, offer greater promise in terms of decreasing erosion and maintaining or even increasing yields (Lal, 1990). While some information is available on the effects of mechanical systems on soil erosion in Malawi (Amphlett, 1990), little is known about their construction and maintenance costs and their impact on yields. Similarly, although much research

inputs, and thus costs, either initially and/or on a regular basis, in return for higher yields and revenues. Initial costs, both financial and in terms of labour, can be quite substantial and are arguably the main constraint facing farmers wishing to adopt soil-conserving cropping systems. It is possible to imagine therefore that the results would be somewhat similar to those produced for the no-till system. For the smallholder sector cultivating local maize without fertiliser, the effect on yields might often be too small to outweigh the costs.

An interesting exercise would therefore be to conduct such a simulation using relative levels (percentage increase in investment and recurrent costs, initial level of soil erosion relative to subsequent lower level achieved) as opposed to empirical values, to explore whether any broad conclusions can be drawn. It may be possible to define general rules for when soil conservation activities will appear attractive or not, based on relative values of the parameters.

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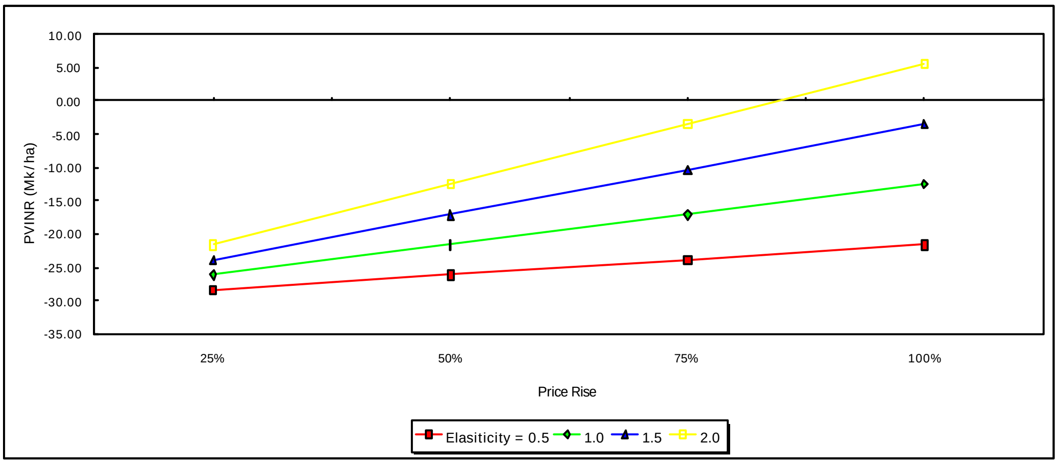
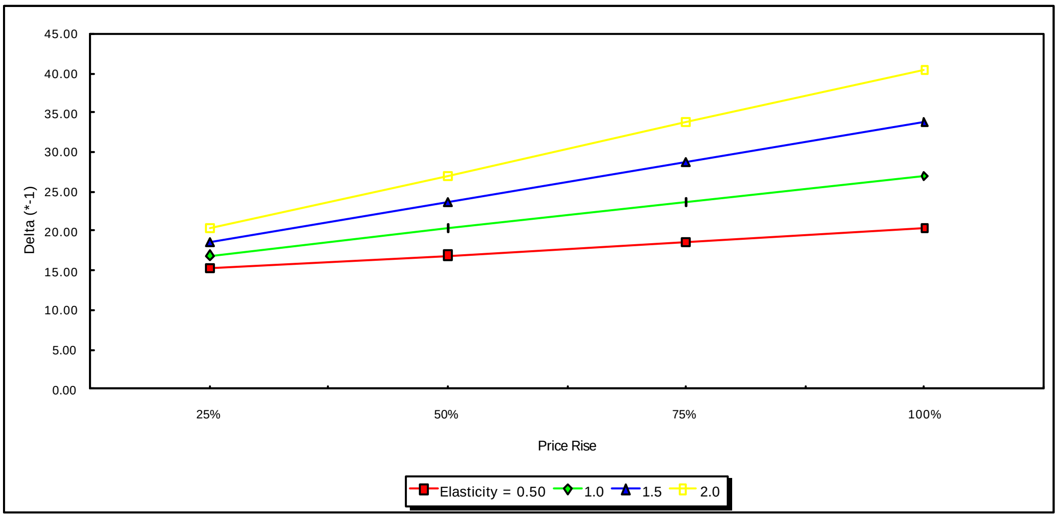
is being undertaken in Malawi on agroforestry systems (Barbier and Burgess, 1992a), data could not be obtained on the costs of such systems. Ehui *et al.* (1990) compared two such systems in their study of Nigeria but did not include any initial capital costs for the alley-cropping systems (purchase of seedlings and labour to plant and tend to them).

### Figure 15: PVINR for the No-till System for Various Output Price Changes and Price Elasticities of Gross Margins



### Figure 16: Delta (*-1) for the No-till System for Various Price Changes and Price Elasticities of Gross Margins



Assumptions for Figures 15 and 16:

Labour fixed
10 year planning horizon
Soil erosion reduced from 20 to 2 t/ha/yr

Cost of herbicide = 30 Mk/ha
Beta = 0.006
10% discount rate

Figure 17: PVINR for the No-till System for Various Output Price Changes and Discount Rates

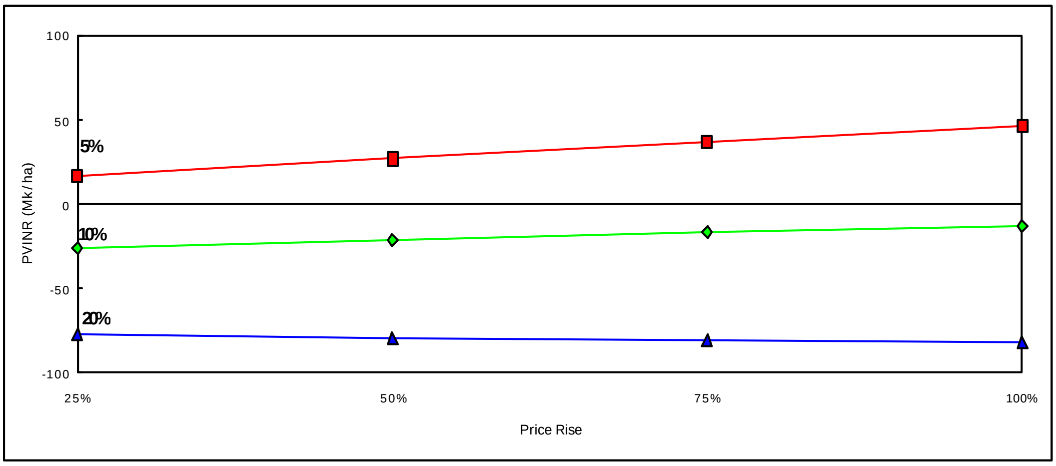
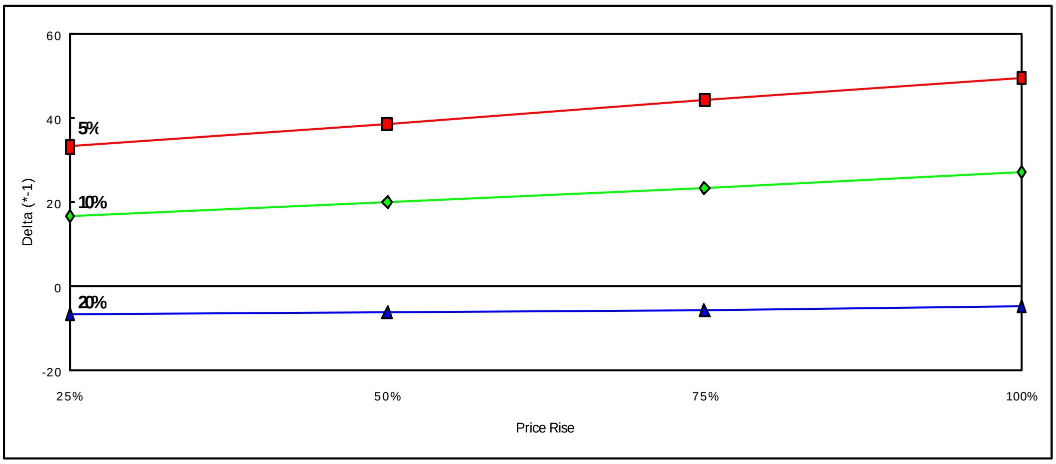


Figure 18: Delta (*-1) for the No-till System for Various Output Price Changes and Discount Rates



| Assumptions for Figures 17 and 18: | Labour fixed | Cost of herbicide = 30 Mk/ha |
|---|---|---|
| | 10 year planning horizon | Beta = 0.006 |
| | Soil erosion reduced from 20 to 2 t/ha/yr | Unitary price elasticity of gross margins |

## 5. CONCLUSION

Empirical analysis of soil erosion and conservation is complicated in physical and agronomic respects. This leads to complex economic analysis as well. Nevertheless, economics has an important role to play in analysing the trade-offs involved in soil conservation. Unfortunately, little empirical work has been carried out on the economics of soil conservation on small farms in developing countries.

This paper emphasises the importance of looking at soil conservation measures as alternative cropping systems with separate production functions. An examination of some of the theoretical models in this area suggests that omitting this critical feature may result in misleading predictions of farmer behaviour. The simulation results offer preliminary evidence of this finding.

The simulation revealed the importance of certain factors in affecting the incentives facing farmers to adopt conservation investments. In particular, the analysis confirms the importance of ongoing costs (such as additional inputs or maintenance costs) of any alternative cropping system, as well as the key role played by the discount rate. For future empirical applications, attention should focus on assessing what these are for farmers in various circumstances. In addition, as mentioned above, the study finds support for the hypothesis that agricultural pricing policies may play a significant role in determining incentives facing farmers regarding conservation. Lastly, the results demonstrate that in a situation of already low yields and low labour productivity in agriculture, soil conserving systems may not be very attractive to the farmer despite significant rates of erosion, because the gains from decreased soil erosion do not translate into substantial additional revenue.

The simulation assumes that credit is not available to the smallholder farmer, based on evidence from Barbier and Burgess (1992a). Use of credit for initial purchases (*eg,* herbicide sprayer) would have a significant effect on the analysis. But such extensions should await the availability of more empirical data on the relationship between erosion, conservation and productivity for at least two reasons: the large number of arbitrary assumptions adopted in order to conduct the simulations; and the lack of sufficient information to model whole farm systems as opposed to single crop budgets.

The simulation also illustrates how different techniques for modelling farmers' perceptions of the costs and benefits of alternative cropping systems can significantly affect the results. More specifically, the simulation demonstrates that Walker's damage function may define the choice of options more accurately than a conventional net present value calculation. Walker's damage function describes the farmer's decision-making process in a dynamic, or iterative, fashion. Indeed, if one characterises the conventional net present value calculation as a typical cost-benefit analysis, then the damage function approach can be seen as a way of altering the starting time for the investment. Additional insights may be obtained from incorporating some of the recent work on investment theory (Dixit and Pindyck 1994) so that the uncertainty – of future prices, costs and yields – faced by African farmers in assessing the timing of any conservation investment could be included in the analysis.

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# 7. APPENDIX

## LIST OF TABLES

## Table 1: Simulation of Gross Margins from Maize Cultivation (without fertilizer)

**Gross Margin; Labour fixed (Mk/ha)**

| Year | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Beta** | | | | | | | | | | | | | | | | | | | | |
| **0.002** | 90.63 | 87.08 | 83.66 | 80.38 | 77.23 | 74.20 | 71.29 | 68.50 | 65.81 | 63.23 | 60.75 | 58.37 | 56.08 | 53.88 | 51.77 | 49.74 | 47.79 | 45.91 | 44.11 | 42.38 |
| **0.004** | 90.63 | 83.66 | 77.23 | 71.29 | 65.81 | 60.75 | 56.08 | 51.77 | 47.79 | 44.11 | 40.72 | 37.59 | 34.70 | 32.03 | 29.57 | 27.30 | 25.20 | 23.26 | 21.47 | 19.82 |
| **0.006** | 90.63 | 80.38 | 71.29 | 63.23 | 56.08 | 49.74 | 44.11 | 39.13 | 34.70 | 30.78 | 27.30 | 24.21 | 21.47 | 19.04 | 16.89 | 14.98 | 13.29 | 11.78 | 10.45 | 9.27 |
| **0.010** | 90.63 | 74.20 | 60.75 | 49.74 | 40.72 | 33.34 | 27.30 | 22.35 | 18.30 | 14.98 | 12.27 | 10.04 | 8.22 | 6.73 | 5.51 | 4.51 | 3.69 | 3.02 | 2.47 | 2.02 |
| **0.015** | 90.63 | 67.14 | 49.74 | 36.85 | 27.30 | 20.22 | 14.98 | 11.10 | 8.22 | 6.09 | 4.51 | 3.34 | 2.47 | 1.83 | 1.35 | 1.00 | 0.74 | 0.55 | 0.40 | 0.30 |

**Gross Margin; Labour variable (Mk/ha)**

| Year | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Beta** | | | | | | | | | | | | | | | | | | | | |
| **0.002** | 57.13 | 54.89 | 52.74 | 50.67 | 48.68 | 46.77 | 44.94 | 43.18 | 41.48 | 39.86 | 38.30 | 36.79 | 35.35 | 33.96 | 32.63 | 31.35 | 30.12 | 28.94 | 27.81 | 26.72 |
| **0.004** | 57.13 | 52.74 | 48.68 | 44.94 | 41.48 | 38.30 | 35.35 | 32.63 | 30.12 | 27.81 | 25.67 | 23.70 | 21.87 | 20.19 | 18.64 | 17.21 | 15.88 | 14.66 | 13.54 | 12.50 |
| **0.006** | 57.13 | 50.67 | 44.94 | 39.86 | 35.35 | 31.35 | 27.81 | 24.66 | 21.87 | 19.40 | 17.21 | 15.26 | 13.54 | 12.01 | 10.65 | 9.44 | 8.37 | 7.42 | 6.58 | 5.84 |
| **0.010** | 57.13 | 46.77 | 38.30 | 31.35 | 25.67 | 21.02 | 17.21 | 14.09 | 11.53 | 9.44 | 7.73 | 6.33 | 5.18 | 4.24 | 3.47 | 2.84 | 2.32 | 1.90 | 1.56 | 1.27 |
| **0.015** | 57.13 | 42.32 | 31.35 | 23.23 | 17.21 | 12.75 | 9.44 | 6.99 | 5.18 | 3.83 | 2.84 | 2.10 | 1.56 | 1.15 | 0.85 | 0.63 | 0.47 | 0.34 | 0.25 | 0.19 |

Assumptions:

Yield: 850 kg/ha
Price: 12.22 t/kg
Gross return: 103.87 Mk/ha
Soil Loss: 20 t/ha/yr

Total Variable Costs: 13.24 Mk/ha (excluding labour)
Labour Costs: 33.50 Mk/ha
Fixed Costs: 8.39 Mk/ha

## Table 2: Simulation of Net Income from Maize Cultivation (without fertilizer)

**Net Income; Labour fixed (Mk/ha)**

| Year | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Beta** | | | | | | | | | | | | | | | | | | | | |
| **0.002** | 48.74 | 45.19 | 41.77 | 38.49 | 35.34 | 32.31 | 29.40 | 26.61 | 23.92 | 21.34 | 18.86 | 16.48 | 14.19 | 11.99 | 9.88 | 7.85 | 5.90 | 4.02 | 2.22 | 0.49 |
| **0.004** | 48.74 | 41.77 | 35.34 | 29.40 | 23.92 | 18.86 | 14.19 | 9.88 | 5.90 | 2.22 | -1.17 | -4.30 | -7.19 | -9.86 | -12.32 | -14.59 | -16.69 | -18.63 | -20.42 | -22.07 |
| **0.006** | 48.74 | 38.49 | 29.40 | 21.34 | 14.19 | 7.85 | 2.22 | -2.76 | -7.19 | -11.11 | -14.59 | -17.68 | -20.42 | -22.85 | -25.00 | -26.91 | -28.60 | -30.11 | -31.44 | -32.62 |
| **0.010** | 48.74 | 32.31 | 18.86 | 7.85 | -1.17 | -8.55 | -14.59 | -19.54 | -23.59 | -26.91 | -29.62 | -31.85 | -33.67 | -35.16 | -36.38 | -37.38 | -38.20 | -38.87 | -39.41 | -39.86 |
| **0.015** | 48.74 | 25.25 | 7.85 | -5.04 | -14.59 | -21.67 | -26.91 | -30.79 | -33.67 | -35.80 | -37.38 | -38.55 | -39.41 | -40.06 | -40.53 | -40.88 | -41.14 | -41.34 | -41.48 | -41.59 |

**Net Income; Labour variable (Mk/ha)**

| Year | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Beta** | | | | | | | | | | | | | | | | | | | | |
| **0.002** | 48.74 | 46.50 | 44.35 | 42.28 | 40.29 | 38.38 | 36.55 | 34.79 | 33.09 | 31.47 | 29.91 | 28.40 | 26.96 | 25.57 | 24.24 | 22.96 | 21.73 | 20.55 | 19.42 | 18.33 |
| **0.004** | 48.74 | 44.35 | 40.29 | 36.55 | 33.09 | 29.91 | 26.96 | 24.24 | 21.73 | 19.42 | 17.28 | 15.31 | 13.48 | 11.80 | 10.25 | 8.82 | 7.49 | 6.27 | 5.15 | 4.11 |
| **0.006** | 48.74 | 42.28 | 36.55 | 31.47 | 26.96 | 22.96 | 19.42 | 16.27 | 13.48 | 11.01 | 8.82 | 6.87 | 5.15 | 3.62 | 2.26 | 1.05 | -0.01 | -0.96 | -1.80 | -2.55 |
| **0.010** | 48.74 | 38.38 | 29.91 | 22.96 | 17.28 | 12.63 | 8.82 | 5.70 | 3.14 | 1.05 | -0.66 | -2.06 | -3.21 | -4.15 | -4.92 | -5.55 | -6.06 | -6.48 | -6.83 | -7.11 |
| **0.015** | 48.74 | 33.93 | 22.96 | 14.84 | 8.82 | 4.36 | 1.05 | -1.39 | -3.21 | -4.55 | -5.55 | -6.28 | -6.83 | -7.23 | -7.53 | -7.76 | -7.92 | -8.04 | -8.13 | -8.20 |

Assumptions:

Yield: 850 kg/ha
Price: 12.22 t/kg
Gross return: 103.87 Mk/ha
Soil Loss: 20 t/ha/yr

Total Variable Costs: 13.24 Mk/ha (excluding labour)
Labour Costs: 33.50 Mk/ha
Fixed Costs: 8.39 Mk/ha

**Table 3:** **Economic Productive Life of Soil in Years - Local Maize No Fertilizer**

| Soil Loss (t/ha/pa) | Beta (labour fixed) | | | | | Beta (labour variable) | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | 0.002 | 0.004 | 0.006 | 0.01 | 0.015 | 0.002 | 0.004 | 0.006 | 0.01 | 0.015 |
| 2 | 193 | 97 | 65 | 39 | 26 | 480 | 240 | 160 | 96 | 64 |
| 5 | 78 | 39 | 26 | 16 | 11 | 192 | 96 | 64 | 39 | 26 |
| 10 | 39 | 20 | 13 | 8 | 6 | 96 | 48 | 32 | 20 | 13 |
| 15 | 26 | 13 | 9 | 6 | 4 | 64 | 32 | 22 | 13 | 9 |
| 20 | 20 | 10 | 7 | 4 | 3 | 48 | 24 | 16 | 10 | 7 |
| 25 | 16 | 8 | 6 | 4 | 3 | 39 | 20 | 13 | 8 | 6 |
| 30 | 13 | 7 | 5 | 3 | 2 | 32 | 16 | 11 | 7 | 5 |

**Table 4:** **Economic Productive Life of Soil in Years - Local Maize No Fertilizer for 50% Output Price rise for various price elasticities of gross margins given soil loss of 20 t/ha/yr**

| Elasticity | Beta (labour fixed) | | | | | Beta (labour variable) | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | 0.002 | 0.004 | 0.006 | 0.01 | 0.015 | 0.002 | 0.004 | 0.006 | 0.01 | 0.015 |
| 0.50 | 25 | 13 | 9 | 5 | 4 | 54 | 27 | 18 | 11 | 8 |
| 0.75 | 28 | 14 | 10 | 6 | 4 | 56 | 28 | 19 | 12 | 8 |
| 1.00 | 30 | 15 | 10 | 6 | 4 | 59 | 30 | 20 | 12 | 8 |
| 1.25 | 32 | 16 | 11 | 7 | 5 | 61 | 31 | 21 | 13 | 9 |
| 1.50 | 34 | 17 | 12 | 7 | 5 | 62 | 31 | 21 | 13 | 9 |
| 2.00 | 37 | 19 | 13 | 8 | 5 | 66 | 33 | 22 | 14 | 9 |
| 3.00 | 43 | 22 | 15 | 9 | 6 | 71 | 36 | 24 | 15 | 10 |
| 5.00 | 51 | 26 | 17 | 11 | 7 | 80 | 40 | 27 | 16 | 11 |

**Table 5:** **Economic Productive Life of Soil in Years - Local Maize No Fertilizer for 25% Output Price rise for various price elasticities of gross margins given soil loss of 20 t/ha/yr**

| Elasticity | Beta (labour fixed) | | | | | Beta (labour variable) | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | 0.002 | 0.004 | 0.006 | 0.01 | 0.015 | 0.002 | 0.004 | 0.006 | 0.01 | 0.015 |
| 0.50 | 23 | 12 | 8 | 5 | 3 | 51 | 26 | 17 | 11 | 7 |
| 0.75 | 24 | 12 | 8 | 5 | 4 | 53 | 27 | 18 | 11 | 7 |
| 1.00 | 25 | 13 | 9 | 5 | 4 | 54 | 27 | 18 | 11 | 8 |
| 1.25 | 27 | 14 | 9 | 6 | 4 | 55 | 28 | 19 | 11 | 8 |
| 1.50 | 28 | 14 | 10 | 6 | 4 | 56 | 28 | 19 | 12 | 8 |
| 2.00 | 30 | 15 | 10 | 6 | 4 | 59 | 30 | 20 | 12 | 8 |
| 3.00 | 34 | 17 | 12 | 7 | 5 | 62 | 31 | 21 | 13 | 9 |
| 5.00 | 40 | 20 | 14 | 8 | 6 | 69 | 35 | 23 | 14 | 10 |

**Table 6:** **Economic Productive Life of Soil in Years - Local Maize No Fertilizer for various output price rises given unitary price elasticity of gross margins given soil loss of 20 t/ha/yr**

| Price rise | Beta (labour fixed) | | | | | Beta (labour variable) | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | 0.002 | 0.004 | 0.006 | 0.01 | 0.015 | 0.002 | 0.004 | 0.006 | 0.01 | 0.015 |
| 25% | 25 | 13 | 9 | 5 | 4 | 54 | 27 | 18 | 11 | 8 |
| 50% | 30 | 15 | 10 | 6 | 4 | 59 | 30 | 20 | 12 | 8 |
| 75% | 34 | 17 | 12 | 7 | 5 | 62 | 31 | 21 | 13 | 9 |
| 100% | 37 | 19 | 13 | 8 | 5 | 66 | 33 | 22 | 14 | 9 |
| 200% | 47 | 24 | 16 | 10 | 7 | 76 | 38 | 26 | 16 | 11 |
| 300% | 54 | 27 | 18 | 11 | 8 | 83 | 42 | 28 | 17 | 12 |
| 500% | 65 | 33 | 22 | 13 | 9 | 93 | 47 | 31 | 19 | 13 |

Table 7: **Economic Productive Life of Soil in Years - Local Maize No Fertilizer for various output price rises and price elasticities of gross margins given Beta = 0.002, soil loss of 20 t/ha/yr and labour fixed**

| | Price elasticity of gross margin | | | | | | |
|---|---|---|---|---|---|---|---|
| Price rise | 0.25 | 0.50 | 0.75 | 1.00 | 2.00 | 3.00 | 5.00 |
| 25% | 21 | 23 | 24 | 25 | 30 | 34 | 40 |
| 50% | 23 | 25 | 28 | 30 | 37 | 43 | 51 |
| 75% | 24 | 28 | 31 | 34 | 43 | 49 | 59 |
| 100% | 25 | 30 | 34 | 37 | 47 | 54 | 65 |
| 200% | 30 | 37 | 43 | 47 | 60 | 68 | 80 |
| 300% | 34 | 43 | 49 | 54 | 68 | 77 | 89 |
| 500% | 40 | 51 | 59 | 65 | 80 | 89 | 101 |

Table 8: **Economic Productive Life of Soil in Years - Local Maize No Fertilizer for various output price rises and price elasticities of gross margins given Beta = 0.015, soil loss of 20 t/ha/yr and labour fixed**

| | Price elasticity of gross margin | | | | | | |
|---|---|---|---|---|---|---|---|
| Price rise | 0.25 | 0.50 | 0.75 | 1.00 | 2.00 | 3.00 | 5.00 |
| 25% | 3 | 3 | 4 | 4 | 4 | 5 | 6 |
| 50% | 3 | 4 | 4 | 4 | 5 | 6 | 7 |
| 75% | 4 | 4 | 5 | 5 | 6 | 7 | 8 |
| 100% | 4 | 4 | 5 | 5 | 7 | 8 | 9 |
| 200% | 4 | 5 | 6 | 7 | 8 | 10 | 11 |
| 300% | 5 | 6 | 7 | 8 | 10 | 11 | 12 |
| 500% | 6 | 7 | 8 | 9 | 11 | 12 | 14 |

Table 9: **Economic Productive Life of Soil in Years - Local Maize No Fertilizer for various output price rises and price elasticities of gross margins given Beta = 0.002, soil loss of 20 t/ha/yr and labour variable**

| | Price elasticity of gross margin | | | | | | |
|---|---|---|---|---|---|---|---|
| Price rise | 0.25 | 0.50 | 0.75 | 1.00 | 2.00 | 3.00 | 5.00 |
| 25% | 50 | 51 | 53 | 54 | 59 | 62 | 69 |
| 50% | 51 | 54 | 56 | 59 | 66 | 71 | 80 |
| 75% | 53 | 56 | 60 | 62 | 71 | 78 | 87 |
| 100% | 54 | 59 | 62 | 66 | 76 | 83 | 93 |
| 200% | 59 | 66 | 71 | 76 | 89 | 97 | 108 |
| 300% | 62 | 71 | 78 | 83 | 97 | 106 | 118 |
| 500% | 69 | 80 | 87 | 93 | 108 | 118 | 130 |

Table 10: **Economic Productive Life of Soil in Years - Local Maize No Fertilizer for various output price rises and price elasticities of gross margins given Beta = 0.015, soil loss of 20 t/ha/yr and labour variable**

| | Price elasticity of gross margin | | | | | | |
|---|---|---|---|---|---|---|---|
| Price rise | 0.25 | 0.50 | 0.75 | 1.00 | 2.00 | 3.00 | 5.00 |
| 25% | 7 | 7 | 7 | 8 | 8 | 9 | 10 |
| 50% | 7 | 8 | 8 | 8 | 9 | 10 | 11 |
| 75% | 7 | 8 | 8 | 9 | 10 | 11 | 12 |
| 100% | 8 | 8 | 9 | 9 | 11 | 12 | 13 |
| 200% | 8 | 9 | 10 | 11 | 12 | 13 | 15 |
| 300% | 9 | 10 | 11 | 12 | 13 | 15 | 16 |
| 500% | 10 | 11 | 12 | 13 | 15 | 16 | 18 |

**Table 11:** **Economic Productive Life of Soil in Years - Local Maize with Fertilizer**

| **Soil Loss** (t/ha/pa) | **Beta (labour fixed)** | | | | | **Beta (labour variable)** | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | 0.002 | 0.004 | 0.006 | 0.01 | 0.015 | 0.002 | 0.004 | 0.006 | 0.01 | 0.015 |
| **2** | 168 | 84 | 56 | 34 | 23 | 439 | 220 | 147 | 88 | 59 |
| **5** | 68 | 34 | 23 | 14 | 9 | 176 | 88 | 59 | 36 | 24 |
| **10** | 34 | 17 | 12 | 7 | 5 | 88 | 44 | 30 | 18 | 12 |
| **15** | 23 | 12 | 8 | 5 | 3 | 59 | 30 | 20 | 12 | 8 |
| **20** | 17 | 9 | 6 | 4 | 3 | 44 | 22 | 15 | 9 | 6 |
| **25** | 14 | 7 | 5 | 3 | 2 | 36 | 18 | 12 | 8 | 5 |
| **30** | 12 | 6 | 4 | 3 | 2 | 30 | 15 | 10 | 6 | 4 |

**Table 12:** **Economic Productive Life of Soil in Years - Composite Maize with Fertilizer**

| **Soil Loss** (t/ha/pa) | **Beta (labour fixed)** | | | | | **Beta (labour variable)** | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | 0.002 | 0.004 | 0.006 | 0.01 | 0.015 | 0.002 | 0.004 | 0.006 | 0.01 | 0.015 |
| **2** | 219 | 110 | 73 | 44 | 30 | 587 | 294 | 196 | 118 | 79 |
| **5** | 88 | 44 | 30 | 18 | 12 | 235 | 118 | 79 | 47 | 32 |
| **10** | 44 | 22 | 15 | 9 | 6 | 118 | 59 | 40 | 24 | 16 |
| **15** | 30 | 15 | 10 | 6 | 4 | 79 | 40 | 27 | 16 | 11 |
| **20** | 22 | 11 | 8 | 5 | 3 | 59 | 30 | 20 | 12 | 8 |
| **25** | 18 | 9 | 6 | 4 | 3 | 47 | 24 | 16 | 10 | 7 |
| **30** | 15 | 8 | 5 | 3 | 2 | 40 | 20 | 14 | 8 | 6 |

**Table 13:** **Economic Productive Life of Soil in Years - Hybrid Maize with Fertilizer**

| **Soil Loss** (t/ha/pa) | **Beta (labour fixed)** | | | | | **Beta (labour variable)** | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | 0.002 | 0.004 | 0.006 | 0.01 | 0.015 | 0.002 | 0.004 | 0.006 | 0.01 | 0.015 |
| **2** | 271 | 136 | 91 | 55 | 37 | 721 | 361 | 241 | 145 | 97 |
| **5** | 109 | 55 | 37 | 22 | 15 | 289 | 145 | 97 | 58 | 39 |
| **10** | 55 | 28 | 19 | 11 | 8 | 145 | 73 | 49 | 29 | 20 |
| **15** | 37 | 19 | 13 | 8 | 5 | 97 | 49 | 33 | 20 | 13 |
| **20** | 28 | 14 | 10 | 6 | 4 | 73 | 37 | 25 | 15 | 10 |
| **25** | 22 | 11 | 8 | 5 | 3 | 58 | 29 | 20 | 12 | 8 |
| **30** | 19 | 10 | 7 | 4 | 3 | 49 | 25 | 17 | 10 | 7 |

**Table 14:** **Economic Productive Life of Soil in Years - Chalimba Groundnuts**

| **Soil Loss** (t/ha/pa) | **Beta (labour fixed)** | | | | | **Beta (labour variable)** | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | 0.002 | 0.004 | 0.006 | 0.01 | 0.015 | 0.002 | 0.004 | 0.006 | 0.01 | 0.015 |
| **2** | 295 | 148 | 99 | 59 | 40 | 783 | 392 | 261 | 157 | 105 |
| **5** | 118 | 59 | 40 | 24 | 16 | 313 | 157 | 105 | 63 | 42 |
| **10** | 59 | 30 | 20 | 12 | 8 | 157 | 79 | 53 | 32 | 21 |
| **15** | 40 | 20 | 14 | 8 | 6 | 105 | 53 | 35 | 21 | 14 |
| **20** | 30 | 15 | 10 | 6 | 4 | 79 | 40 | 27 | 16 | 11 |
| **25** | 24 | 12 | 8 | 5 | 4 | 63 | 32 | 21 | 13 | 9 |
| **30** | 20 | 10 | 7 | 4 | 3 | 53 | 27 | 18 | 11 | 7 |

**Table 15:** **Economic Productive Life of Soil in Years - Manipinta Groundnuts**

| **Soil Loss** (t/ha/pa) | **Beta (labour fixed)** | | | | | **Beta (labour variable)** | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | 0.002 | 0.004 | 0.006 | 0.01 | 0.015 | 0.002 | 0.004 | 0.006 | 0.01 | 0.015 |
| **2** | 160 | 80 | 54 | 32 | 22 | 568 | 284 | 190 | 114 | 76 |
| **5** | 64 | 32 | 22 | 13 | 9 | 227 | 114 | 76 | 46 | 31 |
| **10** | 32 | 16 | 11 | 7 | 5 | 114 | 57 | 38 | 23 | 16 |
| **15** | 22 | 11 | 8 | 5 | 3 | 76 | 38 | 26 | 16 | 11 |
| **20** | 16 | 8 | 6 | 4 | 3 | 57 | 29 | 19 | 12 | 8 |
| **25** | 13 | 7 | 5 | 3 | 2 | 46 | 23 | 16 | 10 | 7 |
| **30** | 11 | 6 | 4 | 3 | 2 | 38 | 19 | 13 | 8 | 6 |

**Table 16:** **Economic Productive Life of Soil in Years - Local maize without fertilizer (70%) and Manipinta Groundnuts (30%)**

| **Soil Loss** (t/ha/pa) | **Beta (labour fixed)** | | | | | **Beta (labour variable)** | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | 0.002 | 0.004 | 0.006 | 0.01 | 0.015 | 0.002 | 0.004 | 0.006 | 0.01 | 0.015 |
| **2** | 64 | 32 | 22 | 13 | 9 | 485 | 243 | 162 | 97 | 65 |
| **5** | 26 | 13 | 9 | 6 | 4 | 194 | 97 | 65 | 39 | 26 |
| **10** | 13 | 7 | 5 | 3 | 2 | 97 | 49 | 33 | 20 | 13 |
| **15** | 9 | 5 | 3 | 2 | 2 | 65 | 33 | 22 | 13 | 9 |
| **20** | 7 | 4 | 3 | 2 | 1 | 49 | 25 | 17 | 10 | 7 |
| **25** | 6 | 3 | 2 | 2 | 1 | 39 | 20 | 13 | 8 | 6 |
| **30** | 5 | 3 | 2 | 1 | 1 | 33 | 17 | 11 | 7 | 5 |

Table 17: Economic Productive Life of Soil - Local Maize No Fertilizer for various output price rises and rates of soil loss with price elasticity of gross margin = 1

| | Soil Loss (t/ha/yr) (labour fixed) | | | | | Soil Loss (t/ha (labour variabl | |
|---|---|---|---|---|---|---|---|
| | 2 | 5 | 10 | 20 | 30 | 2 | 5 |
| **Beta = 0.002** | | | | | | | |
| **Price rise** | | | | | | | |
| **25%** | 249 | 100 | 50 | 25 | 17 | 536 | 215 |
| **50%** | 295 | 118 | 59 | 30 | 20 | 581 | 233 |
| **75%** | 333 | 134 | 67 | 34 | 23 | 620 | 248 |
| **100%** | 367 | 147 | 74 | 37 | 25 | 653 | 262 |
| **200%** | 468 | 188 | 94 | 47 | 32 | 755 | 302 |
| **300%** | 540 | 216 | 108 | 54 | 36 | 827 | 331 |
| **500%** | 641 | 257 | 129 | 65 | 43 | 928 | 372 |
| **Beta = 0.015** | | | | | | | |
| **Price rise** | | | | | | | |
| **25%** | 34 | 14 | 7 | 4 | 3 | 72 | 29 |
| **50%** | 40 | 16 | 8 | 4 | 3 | 78 | 31 |
| **75%** | 45 | 18 | 9 | 5 | 3 | 83 | 34 |
| **100%** | 49 | 20 | 10 | 5 | 4 | 88 | 35 |
| **200%** | 63 | 25 | 13 | 7 | 5 | 101 | 41 |
| **300%** | 72 | 29 | 15 | 8 | 5 | 111 | 45 |
| **500%** | 86 | 35 | 18 | 9 | 6 | 124 | 50 |

Table 18: Economic Productive Life of Soil - Local Maize with Fertilizer for various output price rises and rates of soil loss with price elasticity of gross margin = 1

| | Soil Loss (t/ha/yr) (labour fixed) | | | | | Soil Loss (t/ha/yr) (labour variable) | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | 2 | 5 | 10 | 20 | 30 | 2 | 5 | 10 | 20 | 30 |
| **Beta = 0.002** | | | | | | | | | | |
| **Price rise** | | | | | | | | | | |
| **25%** | 224 | 90 | 45 | 23 | 15 | 495 | 198 | 99 | 50 | 33 |
| **50%** | 270 | 108 | 54 | 27 | 18 | 540 | 216 | 108 | 54 | 36 |
| **75%** | 308 | 124 | 62 | 31 | 21 | 579 | 232 | 116 | 58 | 39 |
| **100%** | 341 | 137 | 69 | 35 | 23 | 612 | 245 | 123 | 62 | 41 |
| **200%** | 443 | 177 | 89 | 45 | 30 | 713 | 286 | 143 | 72 | 48 |
| **300%** | 515 | 206 | 103 | 52 | 35 | 785 | 314 | 157 | 79 | 53 |
| **500%** | 616 | 247 | 124 | 62 | 42 | 887 | 355 | 178 | 89 | 60 |
| **Beta = 0.015** | | | | | | | | | | |
| **Price rise** | | | | | | | | | | |
| **25%** | 30 | 12 | 6 | 3 | 2 | 66 | 27 | 14 | 7 | 5 |
| **50%** | 36 | 15 | 8 | 4 | 3 | 72 | 29 | 15 | 8 | 5 |
| **75%** | 42 | 17 | 9 | 5 | 3 | 78 | 31 | 16 | 8 | 6 |
| **100%** | 46 | 19 | 10 | 5 | 4 | 82 | 33 | 17 | 9 | 6 |
| **200%** | 59 | 24 | 12 | 6 | 4 | 96 | 39 | 20 | 10 | 7 |
| **300%** | 69 | 28 | 14 | 7 | 5 | 105 | 42 | 21 | 11 | 7 |
| **500%** | 83 | 33 | 17 | 9 | 6 | 119 | 48 | 24 | 12 | 8 |

Table 19: **Economic Productive Life of Soil - Composite Maize with Fertilizer for various output price rises and rates of soil loss with price elasticity of gross margin = 1**

| | Soil Loss (t/ha/yr)<br>(labour fixed) | | | | | Soil Loss (t/ha/yr)<br>(labour variable) | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | 2 | 5 | 10 | 20 | 30 | 2 | 5 | 10 | 20 | 30 |
| **Beta = 0.002**<br>Price rise | | | | | | | | | | |
| **25%** | 275 | 110 | 55 | 28 | 19 | 642 | 257 | 129 | 65 | 43 |
| **50%** | 320 | 128 | 64 | 32 | 22 | 688 | 275 | 138 | 69 | 46 |
| **75%** | 359 | 144 | 72 | 36 | 24 | 726 | 291 | 146 | 73 | 49 |
| **100%** | 392 | 157 | 79 | 40 | 27 | 760 | 304 | 152 | 76 | 51 |
| **200%** | 494 | 198 | 99 | 50 | 33 | 861 | 345 | 173 | 87 | 58 |
| **300%** | 565 | 226 | 113 | 57 | 38 | 933 | 374 | 187 | 94 | 63 |
| **500%** | 667 | 267 | 134 | 67 | 45 | 1035 | 414 | 207 | 104 | 69 |
| **Beta = 0.015**<br>Price rise | | | | | | | | | | |
| **25%** | 37 | 15 | 8 | 4 | 3 | 642 | 257 | 129 | 65 | 43 |
| **50%** | 43 | 18 | 9 | 5 | 3 | 688 | 275 | 138 | 69 | 46 |
| **75%** | 48 | 20 | 10 | 5 | 4 | 726 | 291 | 146 | 73 | 49 |
| **100%** | 53 | 21 | 11 | 6 | 4 | 760 | 304 | 152 | 76 | 51 |
| **200%** | 66 | 27 | 14 | 7 | 5 | 861 | 345 | 173 | 87 | 58 |
| **300%** | 76 | 31 | 16 | 8 | 6 | 933 | 374 | 187 | 94 | 63 |
| **500%** | 89 | 36 | 18 | 9 | 6 | 1035 | 414 | 207 | 104 | 69 |

Table 20: **Economic Productive Life of Soil - Hybrid Maize with Fertilizer for various output price rises and rates of soil loss with price elasticity of gross margin = 1**

| | Soil Loss (t/ha/yr)<br>(labour fixed) | | | | | Soil Loss (t/ha/yr)<br>(labour variable) | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | 2 | 5 | 10 | 20 | 30 | 2 | 5 | 10 | 20 | 30 |
| **Beta = 0.002**<br>Price rise | | | | | | | | | | |
| **25%** | 327 | 131 | 66 | 33 | 22 | 777 | 311 | 156 | 78 | 52 |
| **50%** | 372 | 149 | 75 | 38 | 25 | 822 | 329 | 165 | 83 | 55 |
| **75%** | 411 | 165 | 83 | 42 | 28 | 861 | 345 | 173 | 87 | 58 |
| **100%** | 444 | 178 | 89 | 45 | 30 | 894 | 358 | 179 | 90 | 60 |
| **200%** | 546 | 219 | 110 | 55 | 37 | 996 | 399 | 200 | 100 | 67 |
| **300%** | 618 | 247 | 124 | 62 | 42 | 1068 | 427 | 214 | 107 | 72 |
| **500%** | 719 | 288 | 144 | 72 | 48 | 1169 | 468 | 234 | 117 | 78 |
| **Beta = 0.015**<br>Price rise | | | | | | | | | | |
| **25%** | 44 | 18 | 9 | 5 | 3 | 104 | 42 | 21 | 11 | 7 |
| **50%** | 50 | 20 | 10 | 5 | 4 | 110 | 44 | 22 | 11 | 8 |
| **75%** | 55 | 22 | 11 | 6 | 4 | 115 | 46 | 23 | 12 | 8 |
| **100%** | 60 | 24 | 12 | 6 | 4 | 120 | 48 | 24 | 12 | 8 |
| **200%** | 73 | 30 | 15 | 8 | 5 | 133 | 54 | 27 | 14 | 9 |
| **300%** | 83 | 33 | 17 | 9 | 6 | 143 | 57 | 29 | 15 | 10 |
| **500%** | 96 | 39 | 20 | 10 | 7 | 156 | 63 | 32 | 16 | 11 |

**Table 21:** **Economic Productive Life of Soil - Chalimba Groundnuts for various output price rises and rates of soil loss with price elasticity of gross margin = 1**

| | Soil Loss (t/ha/yr) (labour fixed) | | | | | Soil Loss (t/ha/yr) (labour variable) | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | 2 | 5 | 10 | 20 | 30 | 2 | 5 | 10 | 20 | 30 |
| **Beta = 0.002** | | | | | | | | | | |
| **Price rise** | | | | | | | | | | |
| **25%** | 351 | 141 | 71 | 36 | 24 | 838 | 336 | 168 | 84 | 56 |
| **50%** | 397 | 159 | 80 | 40 | 27 | 884 | 354 | 177 | 89 | 59 |
| **75%** | 435 | 174 | 87 | 44 | 29 | 922 | 369 | 185 | 93 | 62 |
| **100%** | 468 | 188 | 94 | 47 | 32 | 956 | 383 | 192 | 96 | 64 |
| **200%** | 570 | 228 | 114 | 57 | 38 | 1057 | 423 | 212 | 106 | 71 |
| **300%** | 642 | 257 | 129 | 65 | 43 | 1129 | 452 | 226 | 113 | 76 |
| **500%** | 743 | 298 | 149 | 75 | 50 | 1230 | 492 | 246 | 123 | 82 |
| **Beta = 0.015** | | | | | | | | | | |
| **Price rise** | | | | | | | | | | |
| **25%** | 47 | 19 | 10 | 5 | 4 | 112 | 45 | 23 | 12 | 8 |
| **50%** | 53 | 22 | 11 | 6 | 4 | 118 | 48 | 24 | 12 | 8 |
| **75%** | 58 | 24 | 12 | 6 | 4 | 123 | 50 | 25 | 13 | 9 |
| **100%** | 63 | 25 | 13 | 7 | 5 | 128 | 51 | 26 | 13 | 9 |
| **200%** | 76 | 31 | 16 | 8 | 6 | 141 | 57 | 29 | 15 | 10 |
| **300%** | 86 | 35 | 18 | 9 | 6 | 151 | 61 | 31 | 16 | 11 |
| **500%** | 100 | 40 | 20 | 10 | 7 | 164 | 66 | 33 | 17 | 11 |

**Table 22:** **Economic Productive Life of Soil - Manipinta Groundnuts for various output price rises and rates of soil loss with price elasticity of gross margin = 1**

| | Soil Loss (t/ha/yr) (labour fixed) | | | | | Soil Loss (t/ha/yr) (labour variable) | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | 2 | 5 | 10 | 20 | 30 | 2 | 5 | 10 | 20 | 30 |
| **Beta = 0.002** | | | | | | | | | | |
| **Price rise** | | | | | | | | | | |
| **25%** | 216 | 87 | 44 | 22 | 15 | 623 | 250 | 125 | 63 | 42 |
| **50%** | 261 | 105 | 53 | 27 | 18 | 669 | 268 | 134 | 67 | 45 |
| **75%** | 300 | 120 | 60 | 30 | 20 | 707 | 283 | 142 | 71 | 48 |
| **100%** | 333 | 134 | 67 | 34 | 23 | 741 | 297 | 149 | 75 | 50 |
| **200%** | 435 | 174 | 87 | 44 | 29 | 842 | 337 | 169 | 85 | 57 |
| **300%** | 507 | 203 | 102 | 51 | 34 | 914 | 366 | 183 | 92 | 61 |
| **500%** | 608 | 243 | 122 | 61 | 41 | 1016 | 407 | 204 | 102 | 68 |
| **Beta = 0.015** | | | | | | | | | | |
| **Price rise** | | | | | | | | | | |
| **25%** | 29 | 12 | 6 | 3 | 2 | 84 | 34 | 17 | 9 | 6 |
| **50%** | 35 | 14 | 7 | 4 | 3 | 90 | 36 | 18 | 9 | 6 |
| **75%** | 40 | 16 | 8 | 4 | 3 | 95 | 38 | 19 | 10 | 7 |
| **100%** | 45 | 18 | 9 | 5 | 3 | 99 | 40 | 20 | 10 | 7 |
| **200%** | 58 | 24 | 12 | 6 | 4 | 113 | 45 | 23 | 12 | 8 |
| **300%** | 68 | 27 | 14 | 7 | 5 | 122 | 49 | 25 | 13 | 9 |
| **500%** | 81 | 33 | 17 | 9 | 6 | 136 | 55 | 28 | 14 | 10 |