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COST-BENEFIT ANALYSIS OF SOIL CONSERVATION

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TABLE OF CONTENTS

THE PROBLEM 2
- The Bio-Physical Setting 2
- The Economic Setting 4

COST-BENEFIT ANALYSIS OF SOIL CONSERVATION 6
- Level of Analysis 7
- Constructing the Analysis 7

BIO-PHYSICAL DATA REQUIREMENTS 9
- Quantifying Degredation Rates and Yield Losses 9
- Inappropriate Approaches 13
- Sources of Data 15

ECONOMIC DATA REQUIREMENTS 15
- Input Levels 15
- Prices 16

AN EXAMPLE FROM KENYA 17
- The Setting 18
- Constructing the Analysis 18
- Results 20
- Sensitivity Analysis 21

EXTENSIONS 23
- Farm-Level Analysis 23
- Social Cost-Benefit Analysis 24
- Regional Analysis 25

CONCLUSIONS 26

COST-BENEFIT ANALYSIS OF SOIL CONSERVATION

The degradation of the soil resource base through misuse or over-use has come to be recognized as an important threat to the sustainability of agricultural production. The situation in developing countries is particularly acute because of their dependence on agriculture. Despite the high level of concern over soil degradation problems, however, very little empirical analysis has been carried out on the actual severity of these problems, their causes, and the best ways to address them. Moreover, what work has been done has been largely theoretical, with little emphasis on practical methodologies to examine the economics of soil conservation under specific, practical conditions. This paper describes one such practical methodology—an application of cost-benefit analysis to soil conservation problems.

The basic principle of the methodology, as in all cost-benefit analysis, is to compare the flows of costs and benefits with and without the proposed intervention—in this case some kind of soil conservation activity. The approach taken here is to consider the proposed interventions from the standpoint of the farmers themselves. Although the primary result of the analysis concerns the profitability of the specific measure, this approach also allows detailed examination of the alternatives open to farmers and the constraints they face in undertaking soil conservation and of numerous policy issues.

The most difficult problems in the analysis of soil conservation arise because of the issue's specific data requirements. Two basic sets of information are required: (a) bio-physical data on the effect of activities on soil, and the effect of degradation on yield; (b) economic data on costs and prices. While the latter are often easily available, the former pose considerable—sometimes insuperable—problems. Since much of the theoretical work comes to the conclusion that whether conservation pays or not under specific conditions is dependent on those conditions, addressing the data problems is fundamental to applied analysis. Many of the principles developed herein will be more broadly applicable to numerous other natural resource problems; some, however, are relatively specific to soil conservation problems.

The report begins with an overview of the principal aspects of soil degradation problems, bringing out its salient features from an economic viewpoint. The report then discusses how a cost-benefit analysis of these problems might be structured. The following section examines different approaches to obtaining the necessary data on the bio-physical aspects of the problem. A detailed example from Kenya [Pagiola 1990a] is used to illustrate the methodology. A final section examines some possible extensions of the methodology.

1. THE PROBLEM

Two factors distinguish soil conservation (and most resource) problems from other economic problems: First, the characteristics of the natural system play a critical role. The bio-physical characteristics of the setting must be known in detail if the problem is to be understood and addressed. Second, the problem is generally of a cumulative nature. Analysis, therefore, requires an intertemporal framework.

1.1 Bio-Physical Setting

Unlike many other resources, soil is not of interest in and of itself but only insofar as it is required for crop production. Soil is not an end-product, but an input into a production process. Oil and other resources are also inputs, but they have well-defined markets; there are no markets for soil *per se*—only for products produced from the soil. Soil degradation is of interest, therefore, because of what it might mean for productivity on the farm and for possible damages off the farm.

From an economic point of view, *soil* is a composite asset which provides a number of services, such as physical location of production, provision of nutrients, storage of moisture, etc[1]. Some of the components of soil are non-renewable (the actual physical soil) while others are renewable (organic content, moisture level). Some components may be substituted for (for example, by applying fertilizer)[2]. Some services provided by soil are measured as a stock (topsoil depth), others as a flow (nutrient availability).

Soil *degradation* may refer either to a reduction in the level of services provided (reduction in organic content or nutrient levels, loss of topsoil) or to a reduction of the ability of the soil to provide certain services (laterization, loss of topsoil down to parent rock, decreased permeability or ability to store water). Degradation of soil is usually reflected in lower yields or, if compensating measures are taken, in higher costs for a given yield. In the limit there might be a complete loss of the ability to grow crops (technically, economically, or both). Depending on what form the degradation takes, it may or may not be reversible, either naturally or through human intervention. Degradation may not affect all services rendered by soil, or it may affect them unevenly. Different soils will be affected differently by similar conditions. In general, such damage will be *cumulative*; effects of degradation in any one year are often minor or insignificant, but become important as they accumulate over time[3]. The response of crop yield to the level of any given service provided by

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1. For a standard text on soil properties, which places considerable emphasis on soil's *edaphological* properties (that is, its properties in relation to plant production), see Brady [1986].

2. In principle all services provided by soil can be substituted for; for example, hydroponics might eliminate any need for physical soil. In practice, however, only a few substitutions may be economically (as opposed to technically) feasible.

3. There may be cases, however, where the same-year damage to the crop is significant even though the marginal damage to soil productivity is low. For example, erosion might wash away seed and fertilizer, causing significant yield reductions even though the inherent productivity of the soil has changed little.

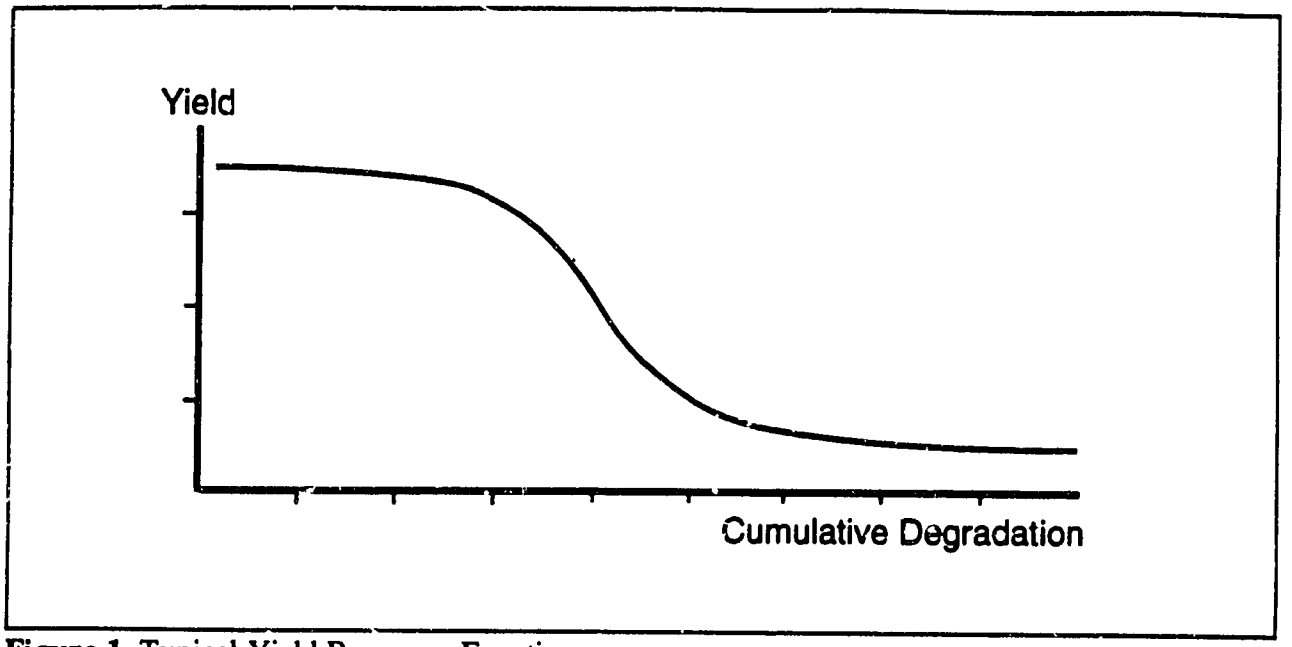

Figure 1. Typical Yield Response Function

the soil is often highly non-linear. In particular, cumulative degradation may have a relatively minor impact on yield until a threshold is reached; additional degradation would then have a much more severe effect on productivity. **[Figure: Yield Response Function]** shows a stylized yield response function; most yield response functions are believed to follow this general form, although the specific parameters of the function vary considerably from case to case. In addition to affecting the productivity of the soil (*on-farm* effects), some forms of degradation may also cause damage of the farm. In particular, erosion often causes economic damage to reservoirs and waterways and to aquatic life within them[4]. Degradation on one farm can also induce or worsen degradation on neighboring farms.

Cultivation often affects soil's properties with regards to crop production adversely. For example, clearing of natural vegetation cover exposes soil to water and wind erosion; repeated tillage destroys soil structure; crop production removes selected nutrients; use of machinery leads to soil compaction. Different practices and crops affect soil differently and to a different extent. Some methods might mitigate damage to soil (minimum tillage), compensate for it (use of fertilizer), repair it (fallow), or attempt to avoid it (various physical conservation measures).

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4. Soil degradation might also damage the functioning of ecological systems. This issue does not arise very often, however, because agricultural environments are already modified from their natural environments. For better or worse, a decision has already been made to use these areas for agricultural purposes and the issue then becomes how best to use them for this end. Ecological concerns are likely to arise, however, when land is newly converted to agriculture. In addition, some types of land use are more ecologically benign than others; conversion to or from these uses would also, therefore, raise ecological issues in addition to economic ones. From the point of view of the analysis herein, such issues are treated as unquantified costs or benefits, to be taken into consideration along with the quantified profitability results in evaluating any given activity.

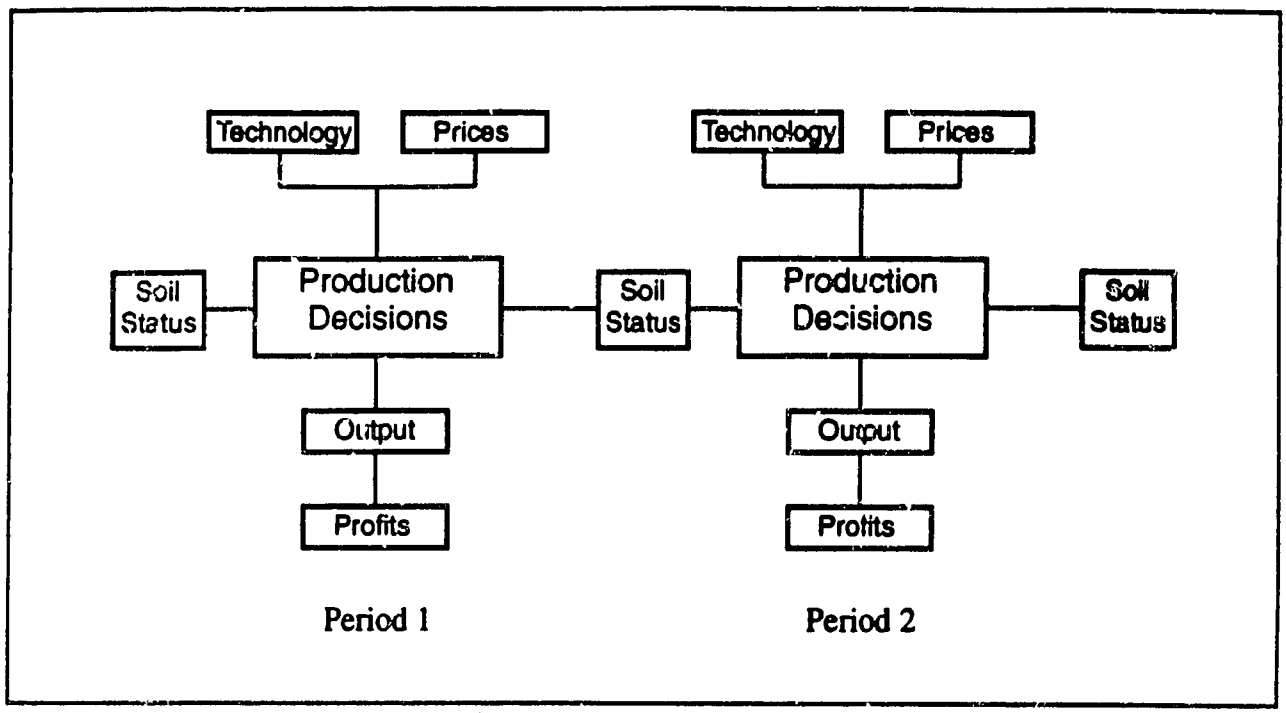

Figure 2. Inter-Temporal Linkages in Farmers Decision-Making

1.2 Economic Setting

Cultivation practices might lead to soil degradation, but they also have desirable aspects such as production of food and fibre. Action to slow or arrest such degradation through changes in crop and management practices or through the adoption of soil conservation techniques is likely to be costly. The critical question is: do the long-term benefits of reduced degradation make these costs worth bearing? The need to ask this question is shown by considering an extreme position sometimes found in the soil conservation literature—that certain fields should not be cultivated at all. If such a practice was adopted, soil erosion might be stopped (natural vegetation generally provides very good protection against erosion), thus preventing future declines in yields. But all benefits from the land would also be foregone. There is little to be gained from maintaining soil productivity if that soil is then left idle.

Consider the production decisions made by farmers in a given year. Their output depends on their technology, their use of inputs, and on the condition of their soil. In a standard single-period profit-maximizing problem, they would treat their soil status as a given, and choose their production level and input use as a function of input and output prices. If cultivation also affects their soil stock, however, their production decisions today will also affect their future production possibilities. This linkage is illustrated in **[Figure: Inter-Temporal Linkages]**.

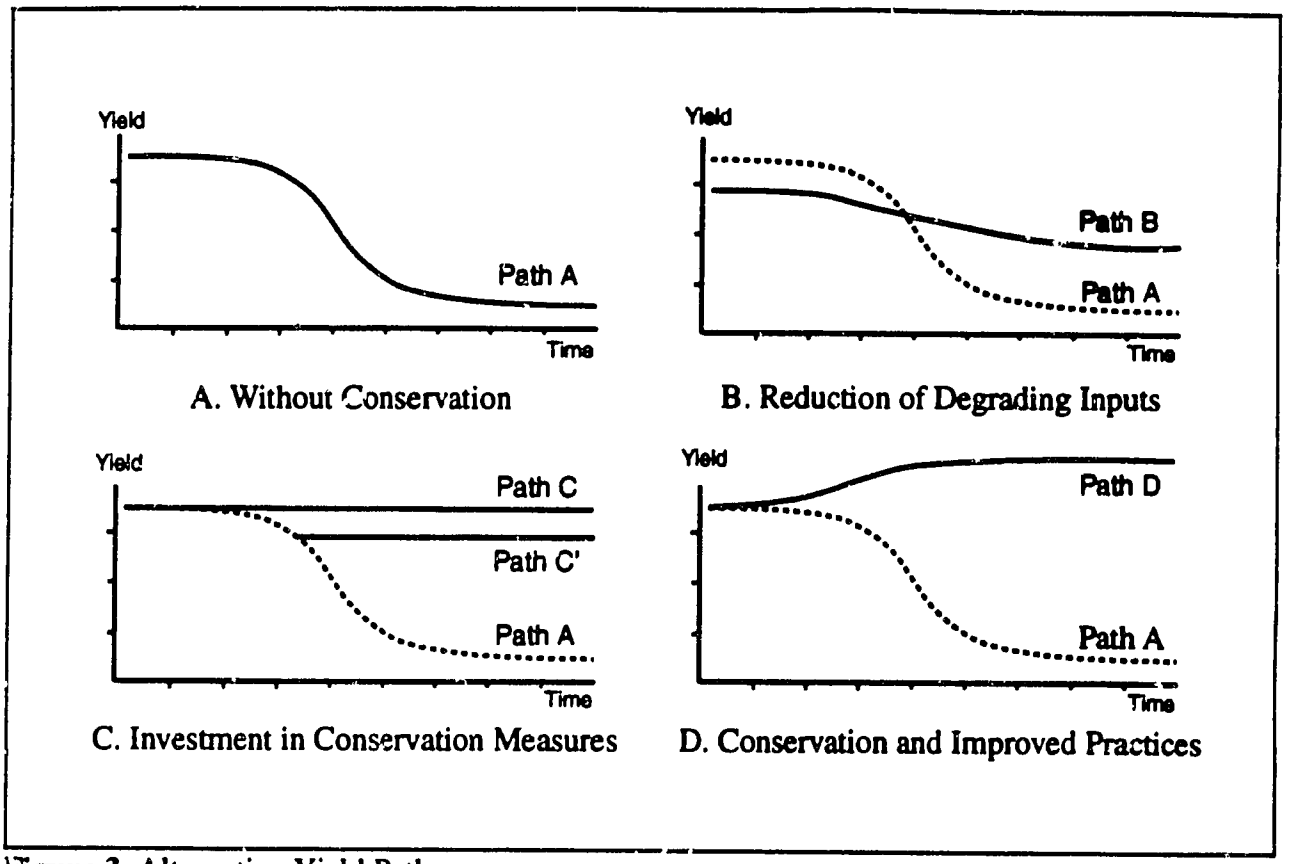

Figure 3. Alternative Yield Paths

In effect, farmers face a choice of following various paths for their future yields. If farmers continue with their, present, degrading practices, their yields will gradually decline, following the appropriate yield response curve, shown in **[Figure: Alternative Yield Paths]** as path A[5]. if they reduce their use of the inputs that cause the degradation (for example by adopting some kind of minimum tillage practice), they might slow their rate of degradation substantially, although they would probably have to accept a lower yield level initially (path B)[6]. If they were to invest in a soil conservation practice (for example, terracing), they might be able to maintain their current yield levels indefinitely, thus shifting to yield path C. In some cases, they might even have options that would not only conserve soil but also lead to yield increases (path D).

5. Note that the x-axis is *time* in this figure, rather than *cumulative degradation*, since degradation rates differ across practices.

6. In general, we assume that the proposed change is less degrading than current practices. Obviously, the opposite case is also possible. For example, a higher-yielding but more degrading practice might be proposed to replace a lower-yielding but more conserving traditional practice. In this case, path B would represent the current practice and A the alternative. The proposed methodology would be equally applicable in determining which path is economically preferable.

In order to make decisions in such a context, farmers need to be able to evaluate the relative benefits of being on each path. Each of these yield paths would involve its own distinct flow of costs and benefits over time. How much does soil degradation cost farmers in terms of lost productivity, or in terms of extra costs? How much would the alternative practices cost in terms of higher costs or lower output levels? Are highly effective but expensive conservation practices more cost-effective than less effective but cheaper conservation practices? Even major degradation problems may not be worth addressing if doing so is very costly. Farmers may also face timing problems: for example, if yield decline would initially be very slow, it may not be economically optimal to implement conservation measures immediately; it might be preferable to allow some degradation to take place and only conserve when the marginal damage caused by additional degradation becomes substantial, even if this results in a lower long-term yield level. This is shown as path C' in **[Figure: Alternative Yield Paths]**.

Evaluating alternative practices is complicated substantially by the inter-temporal nature of the problem. Costs and benefits are borne partly immediately and partly in the future. In particular, the costs of soil conservation investments must usually be borne in the present, but the benefits (in terms of avoided damage from degradation) will not accrue until far in the future. In addition to the cost-effectiveness tradeoffs between practices, therefore, there are also inter-temporal tradeoffs between practices with short-term or long-term benefits.

2. COST-BENEFIT ANALYSIS OF SOIL CONSERVATION

Efforts to examine the economics of soil conservation have often been crude at best. In many cases, rates of soil loss are simply compared against soil loss tolerance values ('T values'). These T values purport to give the maximum rate of soil erosion that would allow a high level of crop productivity to be sustained 'economically and indefinitely' [Wischmeier and Smith 1978]. In practice they are set at levels that approximate what is thought to be the rate of soil regeneration[7] and have practically no economic content. Although the magnitude of costs and benefits resulting from conservation will clearly affect how much conservation is optimal, T values are generally treated as constants. Moreover, T values give no guidance as to the most cost-effective method of reaching this or any other objective.

At the other end of the spectrum, there have been several applications of dynamic optimization techniques, such as optimal control theory, to the soil conservation problem (see, *inter alia* , Burt [1983] and McConnell [1983]). While such techniques have lead to numerous insights concerning optimal soil use, they have been applied almost solely in abstract, stylized settings. Indeed, in many cases, no numerical data are used to even illustrate the results, which remain at a purely theoretical level. Moreover, these results are often ambiguous unless specific assumptions are made about the properties of the bio-physical system; they cannot, therefore, be applied directly to any arbitrary setting.

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7. In fact, considerable uncertainty exists regarding rates of soil generation. For an interesting discussion of the concept and (mis)measurement of T values, see Johnson [1987].

Cost-benefit analysis techniques offer a simple and relatively easily implemented, yet powerful approach to the analysis of soil conservation problems. The method is particularly well suited to applied analysis of specific practical situations. Cost-benefit analysis was originally developed as a tool to examine the economics of projects involving water resource development. Although its application to resource issues was thereafter neglected for some time, it has once again come into widespread use for this purpose [Krutilla and Fisher 1975, Hufschmidt *et al.* 1983]. Variants of this method have been used to examine a number of soil conservation cases: for example, in India [Magrath 1989], in the Dominican Republic [Veloz *et al.* 1985], in Mali [Bishop and Allen 1989], and in several locations in Kenya [Hedfors 1981, Holmberg 1985, Lindgren 1988, Pagiola 1990a].

2.1 Level of Analysis

Although cost-benefit analysis is usually associated with analysis at a fairly aggregated 'project' level, it is not limited to this level of analysis. Indeed, the approach presented here is primarily intended for use at the farm level. This level is chosen for several reasons: First, soil conservation problems are highly site-specific. Aggregating over different bio-physical conditions could lead to misleading results. Second, many soil conservation programs have foundered because of the lack of farmer acceptance. Carrying out the analysis at the farm level increases the likelihood that appropriate programs will be devised and that the constraints faced by farmers will be understood and allowed for. Project-level analysis can then still be carried out by aggregating the results of different farm-level analyses.

A farm-level approach also places the focus firmly on farm productivity effects. In developing countries, where substantial proportions of the population still depend directly on agricultural production, the effect of degradation on yields is usually critical. This is not to belittle the importance, in some situations, of off-farm effects of soil degradation such as siltation of reservoirs and waterways. Even where such off-farm effects are the primary concern, a farm-level approach is appropriate as a first step since conservation measures would have to be implemented on farms.

2.2 Constructing the Analysis

The principle of the analysis is simple: it involves calculating the differences in the flows of costs and benefits between what would happen if current practices continued and what would happen if specified changes in practices were adopted. Formally, let y^e_t be the yield in year t under the erosive practice, and c^e_t be the corresponding annual cost of production. Then the returns obtained each year under the erosive practice are given by $b^e_t = p_t y^e_t - c^e_t$. Similarly, the returns under the conservation practice would be $b^c_t = p_t y^c_t - c^c_t$, where c^c_t is taken to include the annual costs of maintenance to the conservation structures. In addition, adoption of the conservation practice requires an initial investment I^c in the first year to construct the conservation works. The net benefit obtained from adoption of the conservation practice would thus be $b^c_0 - b^e_0 - I^c$ in the first period (denoted as year zero by convention) and $b^c_t - b^e_t$ in every subsequent period, $t = 1,2,...T$.

Typically, the net benefits would be negative in the first period, because of the heavy investment costs. It may then take several more years before the conservation practice is more profitable than the degrading practice, depending on how fast yields decline under the latter. Additional time will then be required before the cumulative benefits from the conservation practice become high enough to pay back the initial investment. Of course, for some measures this may never occur, indicating that adoption of these measures would not be economically profitable for farmers.

In order to compare losses and gains in different periods, they are discounted back to the current period and summed. Taking r as the discount rate, the net benefit, in present value terms, to investing in the soil conservation technique is given by

$$NPV = \sum_{t=0}^{T} (1+r)^{-t} (b^c_t - b^e_t) - I^c.$$

The interpretation is that the soil conservation activity is profitable[8] if NPV>0. It is instructive to expand the formula, giving

$$NPV = \sum_{t=0}^{T} (1+r)^{-t} (p(y^c_t - y^e_t) - (c^c_t - c^e_t)) - I^c.$$

This clearly indicates that the net benefit to be obtained from soil conservation does not depend solely on the yield difference, but also on the price of output (and hence the *value* of the additional yield), on relative costs under each practice, on the magnitude of the initial investment required, and on the discount rate used to weight the returns in different periods.

As with all cost-benefit analysis, there is no pretence of optimization in the method proposed here. Options are considered pairwise, and there is no guarantee that other, unexamined, options would not be preferable to both. However, the method does allow comparison of numerous alternative practices. By comparing the net benefits to be obtained from two or more alternatives, the most profitable can be selected.

The calculations required can be easily carried out in an electronic spreadsheet. A spreadsheet also provides a convenient way of carrying out sensitivity analysis.

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8. NPV is the criterion most commonly used to judge the profitability of the investment. Other criteria exist [see Gittinger 1982 for a full discussion]. For our purposes, the two most useful alternative measures are (i) the internal rate of return (IRR), which is the discount rate under which the net present value is exactly zero—in other words the discount rate i such that

$$\sum_{t=0}^{T} (1+i)^{-t} (b^c_t - b^e_t) - I^c = 0;$$

and (ii) the number of year before the initial investment is repaid—that is, the smallest number of years τ such that

$$\sum_{t=0}^{\tau} (1+r)^{-t} (b^c_t - b^e_t) - I^c \geq 0.$$

3. BIO-PHYSICAL DATA REQUIREMENTS

Understanding the bio-physical framework is critical to evaluating the flow of costs and benefits. The initial step should be to obtain a solid *qualitative* understanding of the problems being experienced, so as to guide the analysis and the choice of appropriate conservation measures. The assistance of experienced soil scientists and agronomists is often invaluable, as is that of the farmers themselves.

For the analysis to proceed, the effect of specified activities on yields over time must be quantified. This might be achieved either directly or by quantifying separately the relationship between the activities and the level of degradation of the soil and that between the soil's level of degradation and its productivity. Unfortunately, our understanding of these relationships is often limited. And even when our understanding is adequate, our ability to quantify them is minimal[9].

3.1 Quantifying Degradation Rates And Yield Losses

In general, there are two ways to estimate the relationships required for the analysis: by direct statistical estimation of the effect on yield of certain observed conditions, and by modelling of the physical environment using (most likely) experimental data. Both approaches have problems and advantages. The statistical approach is generally simpler, in that it requires less detailed scientific knowledge by the analyst. However, in addition to the difficulty of finding appropriate data and the pitfalls of estimation, the method is highly inflexible: results can only be applied to the specific case from which the data were drawn. The modelling approach is more flexible, and it allows parameter values to be drawn from a variety of data sources. However, it requires very detailed knowledge (both qualitatively and quantitatively) of the bio-physical environment; building and validating a complete and realistic model is a non-trivial endeavor. Even calibrating an existing model is far from easy. In practice, the approach (or combination of approaches) followed is likely to be driven by data availability.

Statistical Method

This approach requires a time series of yield for both the unconserved and the conserved practices of interest. In addition, it also requires information on changes of any other variables that might affect yield over the same period. The idea is to estimate the impact of cumulative degradation by running a regression of yield against time and other variables. For this to work, it is important to ensure that the data is drawn from a relatively homogeneous area and that, except for changes captured in the included independent variables, practices and conditions remain essentially unchanged during the period of analysis.

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9. Recent reviews by Lal [1987] and Stocking [1984] provide an overview of the state of knowledge in this field, with specific attention to soil erosion.

Using panel data for annual yield (over several years), input use, and physical characteristics for each of several farms (all of which use the same practice), as well as of rainfall in each year, one could do a regression as follows:

$$YIELD_{it} = \alpha_0 + \alpha_1 YEAR_t + \alpha_2 INPUT_{it} + \alpha_3 SLOPE_i + \alpha_4 RAIN_t + \varepsilon_{it}$$

where t indexes the year and i the farmer, $INPUT_{it}$ is the input use of each farmer in each year, $SLOPE_i$ the physical characteristics of each farm, and $RAIN_t$ the weather conditions in each year (all of which are likely to be vectors of variables rather than single variables) . Although this example uses a linear specification for ease of exposition, it is likely that a non-linear (polynomial or exponential) specification may fit the data better.

The coefficient on $INPUT_{it}$, α_2, would capture the effects of variations in practices, while α_3 would capture the effect of variations in physical characteristics across farms and α_4 that of any variations due to weather variability; the coefficient on $YEAR_t$, α_1, would then capture any trend in yields. For the without-degradation case, the null hypothesis is that α_1 is negative, indicating that yield would decline over time. For the with-conservation case[10], the null hypothesis depends on the type of measure.

Once the equation has been estimated, the yield path for the practice can be predicted by substituting average rainfall and farm characteristics (or the specific characteristics of interest) and using an index for $YEAR$[11]. If the estimated relationship shows a significant effect of the variables reflecting variations in physical conditions, it is often useful to estimate separate paths for a range of such conditions, repeating the economic calculations for each case.

This approach has several problems, including difficulties of estimation and restrictions on the use of its results. In addition to problems of data reliability, estimation encounters numerous difficulties. Capturing the effect of a weak signal, such as that of cumulative degradation, in an environment that is usually very noisy can be exceedingly difficult. Differences in initial conditions and in management levels or weather variability can all swamp the signal from degradation. In order to detect such a signal, observations are required for numerous years, the more so the slower

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10. The effects of the conservation measure on yields would generally be estimated using a separate equation whose form would be similar to that above. However, if the data set contains information on both conserved and unconserved farms, the two effects could be estimated together by using dummy variables and interaction terms. For example, the following terms could be added to the specification above:

$$+ \beta_0 CONS_i + \beta_1(CONS_i * YEAR_t) + \beta_2(CONS_i * INPUT_{it}) + \beta_3(CONS_i * SLOPE_i) + \beta_4(CONS_i * RAIN_t)$$

where $CONS_i$ is a binary variable, with $CONS_i$=1 if the farm is conserved and $CONS_i$=0 if not. The coefficient on the interaction term of conservation and year, β_1, would then show whether the yield trend varied for conserved and unconserved land; a formal statistical test of the hypothesis that it does could be carried out.

11. Note that the initial yield level (that is, the yield observed in year 0 of the analysis or α_0) is the yield in the first year of the data set, not the year before degradation sets in or before conservation is adopted. This level might have to be changed from that estimated to one appropriate to the conditions being investigated.

the process of yield decline. But practices may not remain the same over a long enough period. Even if a signal can be detected, the effect of *YEAR* must often be extrapolated well beyond the observed sample; given the non-linearity of most degradation processes, extrapolation poses particular dangers. Analysis is also limited to the specific conditions where the measurements were made.

Modelling the Bio-Physical Environment

In this approach, a detailed parametric model of the bio-physical environment is developed. The idea is to develop a model which would capture the principal biological and physical relationships at work, and predict yields and the effects of degradation on the basis of a number of physical parameters and values for farmer input levels. Ideally, such models could predict yield effects for a variety of conditions, by entering the appropriate parameter values. Such models range from the relatively simple, such as those based on the Universal Soil Loss Equation (USLE), to the very sophisticated.

Where the problem to be examined is primarily due to erosion, models based on the USLE are often attractive, because of the flexibility of this equation and the considerable amounts of work that have already been carried out on it. The USLE relates soil loss from a field to the climate, type of soil, topography, and management variables as follows:

$$A = RKLSCP$$

Where:

A	is the mean annual soil loss (t/ha)[12],
R	is the erosivity of rainfall (MJ.cm/ha.hr),
K	is the erodibility of the soil (t.hr/MJ.cm),
L	is a factor for the length of the field,
S	is a factor for the slope of the field,
C	is a crop cover and management factor, and
P	is a conservation practices factor.

The core of the USLE gives soil loss as a function of the erosivity of rainfall (R) and the erodibility of soil (K) on a 'standard' plot (slope length 22.6m on a slope of 9% when land use practice is cultivated fallow with plowing up and down the slope). On such a plot, A = RK. Differences in erosion rates due to variations from this standard plot are then obtained from the basic relationship, A = RK, by using proportionality factors. For example, a steeper slope will give a higher rate of erosion. Since the ratio of soil loss on a steeper slope to that on the reference slope is relatively constant, other things equal, this ratio is used to modify the basic soil loss from the reference plot to obtain that of the plot under investigation. In the USLE, the effect of slopes

12. The USLE is generally expressed in Customary English Units (CEU); the units indicated here are for the SI metric version. See Wischmeier and Smith [1978] for conversion factors.

different from the standard slope is given in the slope factor S. Similar factors allow for differences in erosion rates due to slope length, crop and management effects, and adoption of specific conservation practices (the L, C, and P factors)[13]. All factors are set to 1.0 under standard conditions. Using data from a large number of experimental plots, the USDA has developed K factors for several hundred different soil types and LS, C, and P factors for a large variety of topographies and land use practices. A complete and authoritative exposition of the derivation and use of the USLE can be found in Wischmeier and Smith [1978].

The universality of the USLE does not refer to the specific parameters used in it but to its structure; it provides a way of incorporating the many factors that affect soil erosion into a single equation. As has been argued by Hudson [1986, Ch.10], this structure makes the USLE relatively easy to modify for local conditions. Indeed, the USLE has been successfully adapted for use in several countries[14]. The principal task involved is obtaining estimates for its factors which are suitable to the case of interest, since the parameter values supplied by the USDA for the USLE are calibrated to US midwest conditions and cannot, therefore, be used directly in other settings. This is particularly true of rainfall erosivity (R), soil erodibility (K), and crop and management (C) factors, which depend on local agro-climatic conditions[15]. Slope (LS) and conservation (P) factors can be used directly from USDA data [Hudson 1986][16].

The USLE is an advantageous means of expressing available information on erosion because once appropriate values for the factors have been obtained, they can be used in any combination to provide estimates of expected mean soil loss for any given situation.

The second step in the process requires a relationship between cumulative erosion and yield to be estimated. This is generally a much more difficult step, primarily due to a frequent lack of suitable data. It should be stressed that no simple relationship between erosion and yield exists. One cannot assume, for example, that loss of 50% of the topsoil will reduce yields by 50%; nor is it necessarily true that if a loss of 1cm of soil reduces yields by, say, 5%, that a further 1cm of soil loss would lead to an identical yield reduction. Nor are these factors independent of the practices employed. Practices which do not use commercial fertilizer or manure, for example, may be more

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13. The slope length and slope gradient factors L and S are generally combined into a single topographic factor LS.

14. Numerous examples of applications of the USLE to areas outside the USA can be found in El-Swaify, Moldenhauer, and Lo [1985]. For a more detailed example of an application, to Ethiopia, see Hurni [1985].

15. The rainfall erosivity (R) factor is usually measured using the EI_{30} index. Some researchers, among them Hudson [1986], have suggested that other indices might be more appropriate for tropical conditions. The experimental evidence on this matter is mixed. A nomograph has been developed by the USDA to estimate the soil erodibility (K) factor from various physical properties [Wischmeier and Smith 1978], but its applicability to conditions outside the USA is in dispute. Note that if an index other than EI_{30} is used for R, the K factor must be modified accordingly.

16. However, the USDA formula to calculate the slope (S) factor is only valid up to 18%. Although the formula is frequently used on steeper slopes, some results suggest that the resulting S factor is too high [Hurni 1982].

vulnerable to the effects of degradation since they depend more heavily on the natural fertility of the soil. Generally, the required relationships can be obtained only from experiment station work—from desurfacing experiments, for example[17]. Data will generally come in the form of a discrete set of observations of yield on fields having experienced a set (natural or artificial) amount of soil loss. Regression analysis would then be used to obtain a relationship between soil loss and yield. Note also that such experiments typically repeat the trials with a number of alternative practices. If the objective is to evaluate the impact of erosion on farmers' fields, the results from the experimental practices that most closely approximate farmer practices should be used.

Several more sophisticated bio-physical models have been developed that provide a better representation of the effect of erosion and other bio-physical variables on productivity. EPIC [Williams *et al* 1983], is an example of such a model. Many of these models, including EPIC, retain the USLE as their core method of estimating erosion rates. Although such models clearly provide a more accurate simulation of the likely effects of erosion, they generally require very detailed soil information—the values of numerous variables disaggregated by soil horizon, for example. By and large these models are not operational in developing countries contexts.

3.2 Inappropriate Approaches

The availability of suitable data for this analysis has proved to be a significant stumbling block. In many cases, analysts have been forced to adopt approximations or incomplete data to enable any calculations to be carried out. All such approximations introduce possible errors in the measures of productivity effects, and consequently reduce the confidence level of the estimates of profitability. In addition to reducing precision, however, some approximations can also be shown to significantly bias the results of the analysis.

One such approximation that is commonly used consists of using a fixed measure of the yield difference between the alternative practices, which is assumed to remain constant throughout the period of analysis. This fixed measure might be an average of the yield difference over a time period or an observed yield difference at a particular point in time. Use of this measure is appealing because the data requirements are modest and, perhaps most important, the required data can be gathered quickly when the need arises, simply by measuring yields on samples of conserved and unconserved plots. The use of a fixed yield difference in the analysis of the returns to soil conservation can be challenged on many grounds, however. A fixed yield difference is at best only a snapshot of the degradation process, and might hide considerable variation in outcomes. Despite the apparent ease with which data might be collected, significant measurement problems are likely to be encountered, particularly in finding comparable plots. Most important, however, it can also be shown that use of a fixed yield difference can severely distort both the numerical and the

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17. Data from a desurfacing experiment are generally thought to underestimate the severity of productivity decline due to erosion (because nutrients are preferentially carried away under natural erosion conditions), so they should be used with care. Conversely, it has also been suggested [Thomas, personal communication] that such data overestimate the impact because desurfacing removes all the organic matter from the soil, whereas under natural erosion conditions organic matter would continue to regenerate in the upper layers of the remaining soil.

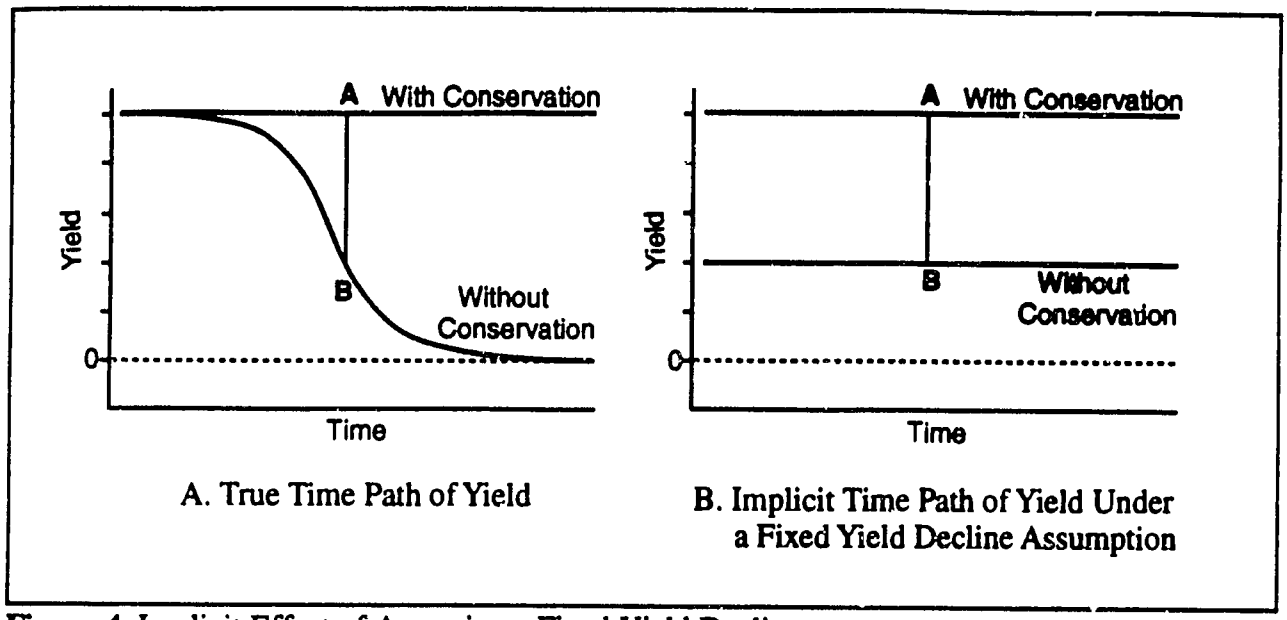

Figure 4. Implicit Effect of Assuming a Fixed Yield Decline

qualitative results of the cost-benefit analysis [Pagiola 1991].

The reason for the distortion can be seen in **[Figure: Implicit Models of Yield Effect]**. Panel A shows the 'true' time path of yield. Without conservation, degradation leads to a gradual decline in yield. At some point, cumulative degradation might drive yields to zero; long before such a point is reached, however, production will have become uneconomic. Conservation could prevent such degradation, leading to little or no change in yields over time, but at some cost. Use of a fixed yield difference, however, is equivalent to assuming that the bio-physical system behaves as in Panel B. Unlike Panel A, the yield effect of degradation does not build up gradually, but occurs immediately. And unlike Panel A, yield does not eventually decline to zero, but rather remains at a constant level indefinitely. These two critical differences mean that analysis based on these two different models of the yield-degradation relationship will lead to very different results.

Consider first the effect of an immediate rather than a gradual yield decline. A gradual decline means that returns to soil conservation, which depend on the difference in yield between conserved and unconserved land, will build up gradually. Conversely, an immediate decline in yield will lead to an immediate jump in the returns to conservation. Since returns which occur later in the period of analysis are weighted less, because of discounting, than returns which occur earlier, the distribution of benefits matters to the ultimate estimate of the returns to conservation. Specifically, the returns to soil conservation will appear to be higher if an immediate rather than a gradual yield effect is assumed, since losses without conservation are brought forward to the heavily-weighted initial period. The effect of shutdown on estimated returns to conservation is slightly different. Cumulative degradation, if left untreated, will eventually cause production to become uneconomic as yields continue to decline, leading the stream of returns under unconserved practices to drop to zero. If a fixed yield difference between conserved and unconserved practices is used, however, and production is at all profitable at the lower yield level, it will be undertaken and continue indefinitely.

This will tend to make the returns to conservation appear to be lower under the latter assumption, since returns to unconserved practices remain positive throughout the period of analysis.

3.3 Sources Of Data

Because agro-ecological conditions are very site-specific, the data required are also very site-specific. Possible data sources include experiment stations, ministry of agriculture records, various projects, local universities, and surveys; sometimes *ad-hoc* surveys can collect suitable data. Often much of the data that is available is too aggregated: it does not distinguish between different conditions and practices. It is impossible to overemphasize the need to be very careful in ensuring that data used are applicable to the case of interest; as the old saw goes, Garbage In, Garbage Out.

4. ECONOMIC DATA REQUIREMENTS

The economic data requirements generally pose much fewer problems. The main need is for crop production budgets, which are used to estimate returns. Although the kind of data required are generally widely available, however, they are often not available at the degree of disaggregation required. Fortunately, preliminary budgets built from available secondary data can usually be confirmed, supplemented, or corrected relatively easily with some additional field work. Several of the points raised here apply to any kind of project for which cost-benefit analysis is being carried; more extensive discussions can be found in numerous sources (Gittinger [1982] is probably the most widely available). Applying cost-benefit analysis to soil conservation issues does raise some distinct issues, however.

4.1 Input Levels

The first step in the construction of appropriate crop production budgets involves estimating the level of use of the various inputs. The most important problem here is to ensure that input levels accurately reflect practices in the area being studied. Even seemingly minor variations in practices can at times have significant effects on the profitability of agriculture and of conservation measures. Though budgets are often available from the Ministry of Agriculture, therefore, verifying them in the field is often advisable.

In cases where the conservation activity being investigated has yet to be implemented in the study area, input levels for this activity will have to be estimated. The problems involved in doing so will vary according to the type of measure being considered. Where the measure consists of constructing a physical conservation work without otherwise changing the practices, the input levels for the degrading activity can be used, and any additional inputs required for conservation added on. Modifications of current budgets might also be adequate for cases involving minor changes to existing practices. As changes to existing practices become more significant, however, entirely new budgets might be required. Basic parameters for such budgets might be obtained from experiment stations or from other regions where similar practices have been implemented. Care is required in using such estimates, however, since actual practice often differs—at times, substantially so—from

experiment station practice and differences in agro-ecological and economic conditions across areas might also induce differences even in seemingly identical practices.

One difficulty involved in the estimating input levels in such an inter-temporal analysis is that they are unlikely to remain constant over the entire period of analysis. On the contrary, the level of various inputs can be expected to adjust as yields change in response to degradation or to conservation measures: Use of complementary inputs will decline, while use of inputs that substitute for soil (such as fertilizers) will increase. At some point, returns under the degrading practice might become so low that cultivation would cease entirely, and the land either be abandoned or converted to a different use. If farmers can be identified who have already experienced different degrees of degradation, their input uses can be compared directly. Otherwise, the specific form that such changes might take could perhaps be obtained by consulting farmers as to their likely responses. Where such fieldwork is not possible, the most common approach is to adjust some inputs, particularly labor, in proportion to yield changes, and to leave all other inputs constant. Such crude approximations are not terribly satisfactory from a formal viewpoint, but generally do not do affect results tremendously. One likely result, however, is that net revenues under the degrading practice will decline faster than they would in reality; the returns to conservation, therefore, will be slightly over-estimated. Provision should also be made in the model for production to either cease or convert to an alternative activity when returns fall beyond a certain point.

Where the conservation practice takes the form of physical structures, engineering calculations are commonly used to estimate the amount of materials and other inputs required. If possible, these should be checked against actual field practice, which sometimes deviates from recommended practice. Deviations from recommended practice might also affect the efficiency of the measure, of course, so this should also be taken into account in estimating the productivity effects of the measures. Comparing estimates of returns to conservation with impeccably (and expensively) constructed physical works to those obtained with more cheaply constructed (and hence less effective) works often reveals interesting trade-offs.

4.2 Prices

As in the case of input levels, the most important need is to ensure that costs and prices used accurately represent the situation in the study area. This generally requires some fieldwork, since the prices found in published budgets are often out of date; moreover, official price data often diverges from prices actually faced by farmers. Selection of appropriate prices involves selection of an appropriate base year for the analysis, since prices in any given year might be distorted from their 'normal' levels for various reasons. Where prices often vary substantially from year to year, or follow a cycle, as in the case of crops such as coffee, it might be desirable to use an average price over the last 5 or so years; the analysis could also be repeated with high and low prices to determine the effects of such fluctuations on returns. Once prices are estimated for a base period, they are usually treated as real prices and kept fixed for the entire period of analysis, unless there is a specific reason to expect relative price changes to occur.

Choosing an appropriate wage rate often poses one of the most difficult problems, since much farming and conservation work is carried out with family labor. Costing this labor often requires analysis of the local labor market. Where labor markets are active and opportunities for work off the farm are reasonably easily available, using the going market wage rate to value family labor is justified, since that wage represents the opportunity cost to the household of time spent on conservation activities. In many instances, however, labor markets are imperfect and/or conservation work is carried out in the off-season, when the opportunity cost of labor is low. Since assumptions made about the wage rate often drive results, given the large share of labor in both production and conservation costs, considerable care needs to be taken in choosing an appropriate wage.

Another price whose choice is critical for the results is that of capital—the discount rate. The choice of an appropriate discount rate has been the subject of considerable controversy since, given the inter-temporal nature of the problem, it will have a very significant effect on the results. At high discount rates, few measures which require heavy initial investments in order to obtain future benefits will appear to be profitable. This is not the place to plunge anew into the polemic over discount rates, which has been discussed extensively in numerous other places (see, *inter alia*, Pierce, Barbier, and Markandya [1990]). For the purpose of the discussion here, the most important point is that the discount rate used will depend on the purpose of the analysis. If the analysis is centered on examining the profitability of conservation from the farmers' viewpoint, then the appropriate discount rate to use is that actually faced by farmers. This is not as simple as it might sound, since farmers generally face highly imperfect capital markets. Here too, detailed knowledge of local capital markets is necessary for accurate estimates. In practice, however, analysts often assume an arbitrary but plausible rate and then carry out sensitivity analysis. Where the purpose of the analysis is to calculate social profitability, then the appropriate discount rate to use is the best estimate of the social opportunity cost of capital; in this case, however, all other prices should also be adjusted to reflect social rather than private opportunity costs. In either case, the rate to use is the *real*, not the nominal discount rate. The internal rate of return provides a useful statistic in cases where the discount rate is particularly uncertain or controversial.

5. AN EXAMPLE FROM KENYA

This section will provide a detailed example of the application of the methodology presented here to soil conservation in Eastern Kenya. The example is based on work carried out by this author [Pagiola 1990a]. The aim of this example is to illustrate the application of the methodology and the interpretation of its results. As in any specific examples, all the problems and issues raised above will not necessarily be encountered here; this does not imply that they may not be important in other contexts.

5.1 The Setting

This example examines the return to terracing in the Kitui/Machakos region, a semi-arid area in Eastern Kenya. Agriculture in the region is mainly subsistence-oriented; most of the land is planted to food crops (primarily maize and beans) for home consumption, with little or no use of commercial inputs. Shifting agriculture had historically been dominant, but increasing population pressure has forced a switch to continuous cultivation. The region is characterized by low, highly variable rainfall distributed in two rainy seasons divided by distinct dry seasons.

Soils in the region are shallow (often with less than 15cm of topsoil), generally deficient in nitrogen and phosphorus, and have low organic matter content. Low infiltration rates and a susceptibility to sealing makes many of the area's soils vulnerable to erosion, particularly since the most intense rains come early in the growing season, when ground cover is poor. The threat of degradation arises primarily from erosion. The recommended practice to avert this threat involves construction of terraces using a locally-developed method known as *fanya juu*, in which a ditch is dug along the contour, with the soil being thrown up to form a ridge above it; a natural bench terrace will then form over the course of the next few years. Other conservation measures, such as trash lines and live barriers, are generally thought to be impractical because of problems with termites and competition with livestock for fodder. The example, therefore, examines the return to investments in terraces.

5.2 Constructing the Analysis[18]

Given the availability of suitable information, the approach adopted was to develop a locally-relevant version of the USLE, and to then relate soil losses to yield decline using a separate, experimentally-derived relationship between topsoil loss and yield. A long-term experiment carried out at the Katumani National Dryland Research Station in the region measured the erodibility of the ferral-chromic luvisol soils (oxic paleustalf in the USDA Soil Taxonomy) found in that area under natural rainfall conditions. The experiment also provided estimates of the crop and management (C) factor and verified that the EI_{30} factor traditionally used to measure rainfall erosivity (R factor) was appropriate in this case. Panel A in **[Table: Parameters for Kenya Example]** shows the USLE parameters used. The slope length and angle assumed are representative of the area. Given these parameters, an average annual soil loss of 57 t/ha is estimated; this is equivalent to an annual loss of 3.7mm of topsoil (the soil's bulk density is 1.52 g/cm^3).

Data from a separate experiment showed the effect of artificial desurfacing of this same soil (to simulate long-term losses from erosion) on maize yields. The limitations of desurfacing experiments were mentioned above; nevertheless, these data were used as no other suitable source was available. Experimental results using the treatment which most closely approximates farmer practice (in which neither manure nor fertilizer are used) are given in Panel B of **[Table:**

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18. Full bibliographic references are given in Pagiola [1990a], which also notes some weaknesses of the data set and the simplifying assumptions that had to be made. For an annotated bibliography on sources relevant to the economic analysis of soil conservation in Kenya, see Pagiola [1990b].

Table 1. Cost-Benefit Analysis of Terracing in Kenya: Parameter Values

A. Relationship Between Practices and Degradation

USLE Parameter		Value
R	Rainfall Erosivity (MJ.cm/ha.hr)	150
K	Soil Erodibility (t.hr/MJ.cm)	0.47
LS	Topography (Slope 10%, Length 20m)	2.10
C	Crop Management (Purestand Maize)	0.77
P	Conservation (Contour Plowing)	0.50

Soil Loss A = RKLSCP
= 57.0 t/ha/yr
= 3.7 mm/ha/yr

B. Relationship Between Degradation and Yield

(First Season Only)

Soil Loss (cm)	Yield (t/ha)
0	1.92
3	1.67
6	1.06
9	0.81
12	0.23
15	0.15

Regression Results (SEs):
Yield = 1.93 - 0.13SoilLoss n = 6, df =4, R^2=0.97
(0.14) (0.01)

Assuming Second Season is 2/3 of First Season:
Yield = 3.2 - 0.22SoilLoss

C. Terrace Construction

Vertical Interval (m)	1.8	Total Terrace Length (m/ha)	856
Horizontal Interval (m)	11.7	Effective Crop Area (%)	95
Terrace Edge Width (m)	0.6		

D. Production Budgets

Input	Price (KSh/Unit)	Without Conservation Quantity (Units/ha)	Without Conservation Cost (KSh/ha)	With Conservation Quantity (Units/ha)	With Conservation Cost (KSh/ha)
Crop Production					
Seed (Kg)	3.0	110	330	110	330
Labor (Mandays)[b]	25.0	180	4500	180	4500
Oxen Rental (KSh)			1050		1050
Total Cost			**5580**		**5580**
Terracing					
Construction (Mandays)[b]	30.0	0	0	107	3210
Maintenance (Mandays)[c]	25.0	0	0	21	535

Notes: a. Declines by 25% of proportional yield fall. b. First year only. c. Second and subsequent years.

Source: Pagiola 1990a and references therein

Parameters for Kenya Example]. Simple linear regression was used to obtain a relationship between yield and soil loss from the data; the results are also given in **[Table: Parameters for Kenya Example]**. In this case, a linear specification provided an excellent fit; this will not generally be true. Since the results apply to a single season, they were increased by 2/3, which is the average ratio of second to first season yields. Given these estimates, an annual soil loss of 3.7mm will cause an annual yield decline of 81Kg. Although this decline may appear small, if nothing is done it will continue year after year, ultimately building up to damaging levels. Within 10 years, yields will have declined by over a quarter. The dimensions of required conservation structures were obtained from manuals used by extension personnel; they are shown in Panel C. Such terraces are assumed to stop erosion entirely and immediately.

Economic parameters for the analysis were collected during several months of fieldwork in the region, and assembled in the form of crop production budgets, shown in Panel D of **[Table: Parameters for Kenya Example]**. Labor and animal traction are the main inputs in each case. Since adoption of conservation involves the addition of terraces but do no other changes in practices, the crop production budgets for the with and without conservation cases are similar. In the without conservation case, however, labor used is assumed to decline as yields fall. Since the majority of labor is devoted to tasks that are not directly related to the yield, labor is assumed to decline by only 25% of the yield decline. Farmer interviews also provided data on costs of terrace construction and maintenance. A 10% discount rate is used in the example.

5.3 Results

[Table: Results of Kenya Example] gives the results of the analysis. Panel A shows the returns to the erosive practice. As cumulative erosion gradually reduces yield, returns decline. Though costs decline slightly as yield-related labor use falls, the damage grows sufficiently rapidly that production becomes unprofitable in the 11th year of the period of analysis. Panel B repeats these calculations for the conservation practice. In this case, erosion is arrested; however, loss of land to terrace edges results in a smaller effective area being cultivated; production, therefore, is initially lower than under the erosive practice. Farmers adopting conservation practice must also bear additional costs due to the initial investment required to construct the terraces and to recurring maintenance costs. Revenues under conservation, therefore, are initially substantially lower than under the erosive practice. However, these revenues remain constant (in nominal terms) over time rather than declining. By the fifth year, yield declines under the erosive practice accumulate to the point that the conservation practice becomes more profitable despite its higher costs. An additional period is then necessary, however, before the accumulated gains from conservation are sufficient to offset the high initial costs. In the example, conservation is not repaid until the 21st year. These results are illustrated in **[Figure: Kenya Results]**.

The interpretation of the results is that farmers in the Kitui/Machakos area *facing conditions such as those specified in the example* would *personally* benefit from adoption of terraces, as indicated by the positive Net Present Value, even if they have to pay the entire cost of conservation themselves. This gain arises from the prevention of future yield losses due to cumulative erosion. This interpretation is only possible since all goods and resources were valued at their actual

Table 2. Cost-Benefit Analysis of Terracing in Kenya: Results

	Units	Year 0	1	2	3	4	5	10	20	30	40	50	100
A. Without Conservation													
Soil Loss	mm	3.7	3.7	3.7	3.7	3.7	3.7	3.7	3.7	3.7	0.0	0.0	0.0
Cumulative Soil Loss	mm	3.7	7.5	11.2	15.0	18.7	22.5	41.2	78.7	116.2	150.0	150.0	150.0
Maize Yield	Kg/ha	3118	3035	2953	2870	2788	2705	2293	1469	645	0	0	0
Maize Yield Index		100.0	97.4	94.7	92.1	89.4	86.8	73.6	47.1	20.7	0.0	0.0	0.0
Revenues	KSh/ha	7794	7588	7382	7176	6970	6763	5733	0	0	0	0	0
Crop production Costs	KSh/ha	5880	5850	5821	5791	5761	5731	5583	0	0	0	0	0
Returns	KSh/ha	1914	1738	1561	1385	1209	1032	151	0	0	0	0	0
Present Value Returns	KSh/ha	1914	1580	1290	1040	825	641	58	0	0	0	0	0
Years Before Shutdown		11											
B. With Conservation													
Maize Yield	Kg/ha	3036	3036	3036	3036	3036	3036	3036	3036	3036	3036	3036	3036
Revenues	KSh/ha	7589	7589	7589	7589	7589	7589	7589	7589	7589	7589	7589	7589
Crop production Costs	KSh/ha	5880	5880	5880	5880	5880	5880	5880	5880	5880	5880	5880	5880
Conservation Costs	KSh/ha	3210	535	535	535	535	535	535	535	535	535	535	535
Returns	KSh/ha	-1500	1174	1174	1174	1174	1174	1174	1174	1174	1174	1174	1174
Present Value Returns	KSh/ha	-1500	1068	970	882	802	729	453	175	67	26	10	0
C. Returns to Conservation													
Net Benefits	KSh/ha	-3414	-563	-387	-211	-34	142	1024	1174	1174	1174	1174	1174
Present Value Net Benefits	KSh/ha	-3414	-512	-320	-158	-23	88	395	175	67	26	10	0
Cumulative Net Benefits	KSh/ha	-3414	-3926	-4246	-4404	-4428	-4340	-2389	-57	1015	1429	1588	1688
NPV at 100 Years	KSh/ha	1688											
Internal Rate of Return	%	12.2											
Years to Break Even		21											

Source. Adapted from Pagiola 1990a

opportunity cost from the farmers' viewpoint, and all construction costs were included in the calculations. In fact, farmers in this area *have* adopted such terraces to a great extent and with very little government assistance, which provides a consistency check on the results. Despite the positive Net Present Value, however, there are causes for concern, including the initial period of low returns, the relatively long pay-back period, and the relatively low internal rate of return (especially since the assumed discount rate is at the low end of the range of estimates for farmers' discount rates).

5.4 Sensitivity Analysis

Sensitivity analysis can be used in two manners: first, to examine whether certain assumptions and/or particularly suspect data have a significant impact on the results; and second, to study the effect of changes in parameter values on the results. The former type of analysis can be illustrated by a test of the sensitivity of the results to the rate of degradation used. This rate might be considered suspect for several reasons: because it is based on a desurfacing experiment, because it is based on yield measurements carried out in only one season, and because experiment station

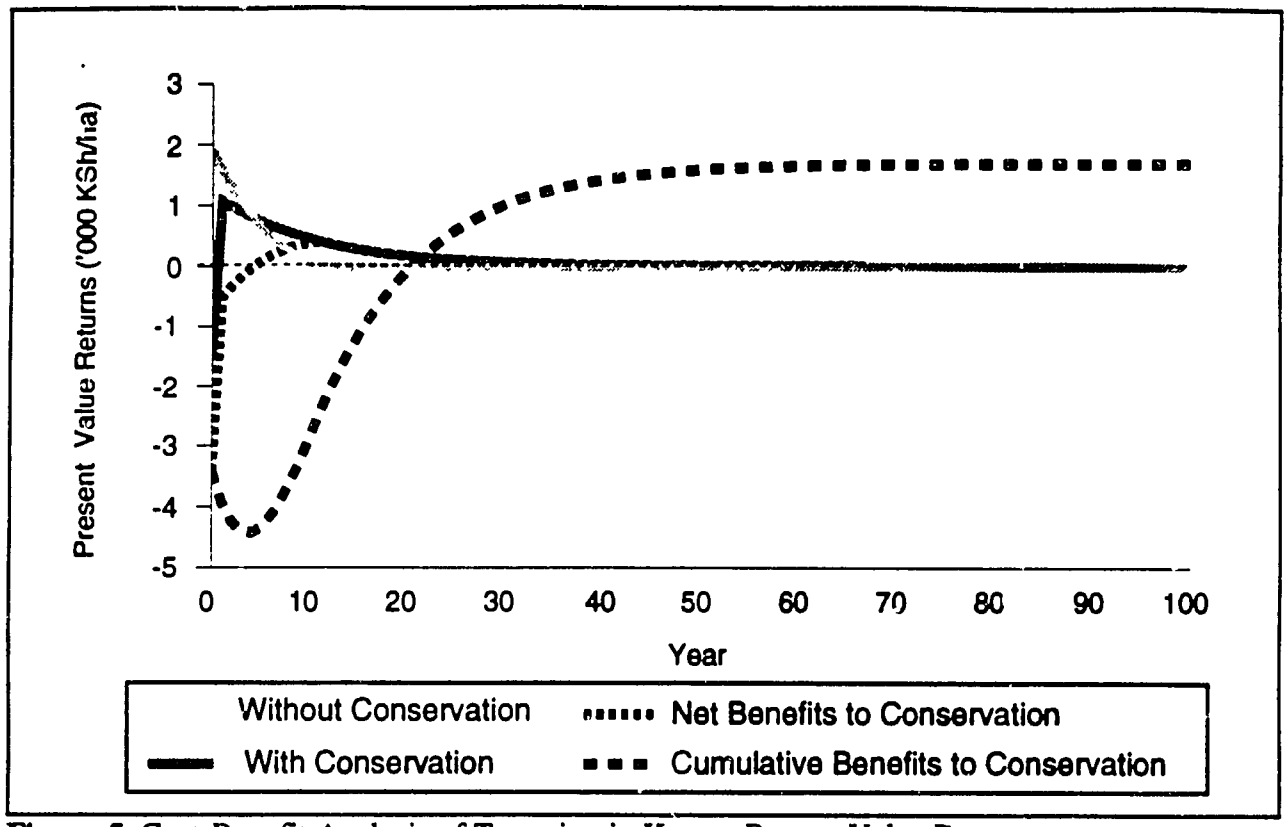

Figure 5. Cost-Benefit Analysis of Terracing in Kenya: Present Value Returns

practices might be different from farmer practices. Reducing the assumed rate by 10% results in the net present value of the returns to conservation falling to just under 1,000KSh/ha and lengthens the period necessary for the investment to be repaid to 27 years. Conversely, a 10% higher rate of degradation increases the NPV to about 2,300KSh/ha and reduces the payback period to 17 years. The results can be seen, therefore, to be relatively sensitive to changes in the assumed rate of degradation, although at least the qualitative results remain unchanged. This is clearly a critical parameter of which more accurate and reliable measures are required.

The second kind of sensitivity analysis is used in a more positive sense to explore the range of conditions under which the measures being examined are profitable. It was stressed earlier that the results only apply to the specific conditions assumed in the example. Although these particular conditions are not unusual, they represent only one point on a spectrum of conditions experienced in the region. Consider the effect of slope on the returns to conservation. At higher slopes, erosion and hence the rate of yield decline will be higher. The cost of conservation will also be higher, however, since narrower terraces will be required, thus increasing both construction and maintenance costs. The net effect of these two factors is shown in **[Figure: Kenya: Effect of Slope]**. Terracing can be seen to be profitable only at slopes above 12%; below this angle, the rate of yield decline is too low to justify incurring the high costs of terrace construction.

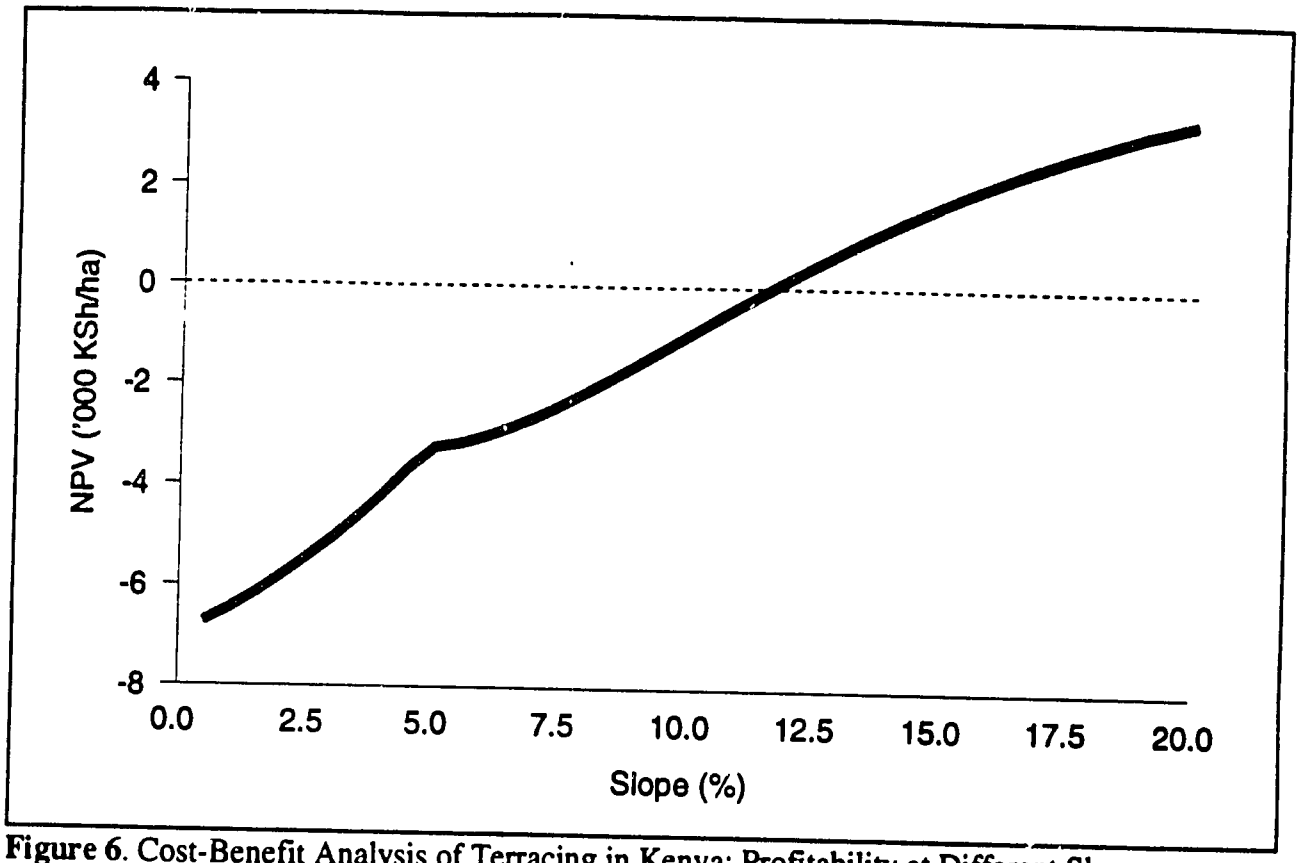

Figure 6. Cost-Benefit Analysis of Terracing in Kenya: Profitability at Different Slopes

6. EXTENSIONS

The basic approach presented here provides a very flexible tool to examine soil conservation problems and, with appropriate modifications, other resource problems. In addition to providing estimates of the profitability or otherwise of specific conservation activities, the calculations required for the analysis can be used directly or with minor alterations to examine a number of issues.

6.1 Farm-Level Analysis

Cost-benefit analysis ignores farmer preferences; nor does it allow for constraints which might be placed by access to resources. It simply states whether it would be in farmers' interest to adopt a particular soil conservation technology under specified circumstances. Only if farmers operate under perfect markets with the sole objective of maximizing profits would such an analysis be sufficient to indicate whether soil conservation would be adopted. Imperfect credit markets, for example, might prevent adoption of costly soil conservation technology even if it were profitable. Although cost-benefit analysis does not directly address these issues, the calculations involved provide important insights into many of them.

- *Credit Constraints* - Soil conservation imposes immediate costs (in terms of actual expenses and, in many cases, of foregone earnings) and brings benefits in the future. Suppose that cost-benefit analysis indicates that investment in a particular conservation practice would be profitable. If the required absolute investment in the initial periods is too high, however, farmers might not be able to undertake it no matter how profitable. As a first cut to this issue, the analysis permits the magnitude of the initial investment and the cash flow generated by the activity to be calculated; this allows analysts to judge whether the sums involved are within the capacity of farmers, either through formal or informal credit markets or through self-finance. Alternatively, the practice could be modified to ease the constraint. For example, conservation might be undertaken gradually over several years. Such an approach might be less profitable—since unconserved land continues to degrade in the meantime—but more likely to be implemented.

- *Tenure Problems* - It has often been argued that conservation practices are not adopted because insecurity of tenure implies that farmers are not sure they will be able to draw the long-term benefits of their investments. In this case, calculating the returns to the activity of interest in terms of the number of years needed to repay the investment can be illuminating, since it permits a comparison between the payback period and the length of tenure. Unless tenure lasts at least as long as the minimum time for the investment to be repaid, farmers are unlikely to undertake it.

6.2 Social Cost-Benefit Analysis

The analysis thus far has been carried out in private terms. That is, it provided estimates of the cost and returns to conservation activities *as perceived directly by farmers.* But private costs and benefits might diverge from the social costs and benefits of soil conservation for two main reasons. First, market failures or policy-induced distortions might distort signals received by farmers. Under such conditions, individual profit-maximizing behavior would not lead to a social optimum. Second, degradation might impose costs on society in addition to the productivity effects on the fields where degradation occurs. If such costs are present, standard economic theory tells us that too little conservation will be undertaken, since farmers will not take them into account in calculating how much they would be willing to pay to avoid a given amount of erosion.

Probably the most important potential divergence in the case of soil conservation concerns the discount rate. We have seen how critical discount rates are to the profitability of soil conservation. Yet credit markets are frequently among the worst functioning markets. Policies which affect the relative profitability of various crops (such as taxes or subsidies) will also affect the returns to soil conservation, since not all crops are equally damaging to the soil. In general such problems can be studied by calculating the returns to soil conservation under both private and social prices and comparing the two. There is an ample literature on procedures to be used to correct observed market prices for distortions (see, *inter alia*, Gittinger [1982] and Monke and Pearson [1989]).

Externalities pose slightly different problems. Examples of such externalities caused by erosion might include the siltation of reservoirs and increased erosion downslope. Such costs were ignored in the preceding discussion but may well be important in particular instances. Quantifying such external damages raises difficult problems that are not dealt with here. This method does allow, however, estimates to be made of the cost of reducing such damage by changes in the activities which cause it. If reduction of downstream damage due to erosion can be achieved through terracing of farmers' fields, for example, the method allows the cost of such an investment to be calculated. Part of this cost will be assigned to preventing declines in productivity. If productivity gains alone are not sufficient to justify the investment, then the negative NPV that will be calculated is an estimate of the minimum subsidy required to induce farmers to adopt the measure anyway[19]. Since there may be alternative measures of reducing the externality by any given amount, the least-cost way of achieving this objective (among the proposed methods) can be identified by comparing their profitabilities. Alternatively, the costs resulting from achieving different levels of reduction in the externality might be compared, to determine the most cost-effective level of abatement.

There has been considerable concern as to the *sustainability* of agricultural production in situations characterized by rapid degradation. Definitions of sustainability vary, but are usually couched in terms of maintaining the volume of *output* over time. It should be clear that the activity identified as most profitable by the method presented here would not necessarily result in sustainability in that sense (although it may). In cases where the most profitable activity is not sustainable, the methodology presented here can answer two types of questions: First, does there exist an alternative practice which is both sustainable and profitable? Second, how much worse off would farmers (at least in the short term) be if they were to adopt the most profitable sustainable practice rather than the absolutely most profitable practice?

6.3 Regional Analysis

The procedure can also be used as a point of departure in estimating the effects of erosion at a more macro level, such as for a region. For example, the method used here could generate expected patterns of degradation and the consequent productivity effects for various synthetic 'representative' farms. A survey of the area of interest could then be used to find out how prevalent each system is; each model would then be weighted appropriately to obtain estimates of trends for the entire area. If calculations are based on a parametric model of the bio-physical environment, a detailed survey could be undertaken in which information on land use and all the relevant parameters for the model are recorded at each point on the survey grid. Calculations could then be made for each such point and the results aggregated to obtain estimates of erosion rates and likely productivity effects for the area as a whole. (If estimates are based on statistical relationships

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19. Judging whether this *per farm* cost of avoiding erosion is worth bearing from a social viewpoint will be difficult because of the considerable uncertainty that exists about the impact of any one farm on the total external damage. Estimates of the delivery ratio (the proportion of total soil eroded that is delivered to the waterway) in any given catchment often differ by orders of magnitude.

between activities and yield, such an approach would only be valid for regions where conditions are very homogeneous.)

Such macro analysis would probably have to take into account endogeneity issues; that is to say, the effects of erosion might change some of the parameter values that describe the situation facing farmers and therefore the future path that they will follow. For example, if all farmers experience degradation, production will decline and prices will rise. This will be very likely to change the relative returns of erosive and conservation practices.

7. CONCLUSIONS

The application of cost-benefit analysis to soil conservation problems described in this paper demonstrates that analysis of resource issues in developing countries is possible even on the basis of relatively limited data. Even so, the data requirements may be difficult to meet in many circumstances, especially in light of the high degree of site-specificity of the problems involved. In such cases, attempting to carry out a coherent, consistent analysis such as that described here will allow gaps and weaknesses in the available data to be identified.

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