The economic assessment of soil nutrient depletion
Analytical issues for framework development

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Contents

Acronyms and abbreviations i
Acknowledgments iii
Preface iv

Summary v
1. Introduction 1
2. The nutrient balance as an indicator of nutrient depletion 3
2.1 The case of subSaharan Africa 5
2.2 Modelling and integration of spatial scales 6
2.3 Limitations of the approach 9
2.4 Relative importance of the different depletion processes 11
3. Towards an economic assessment of nutrient depletion 14
3.1 Nutrient depletion and its socioeconomic environment 14
3.2 Scales of economic assessment 17
3.3 Concepts and considerations 19
3.4 Criteria for method selection 23
4. Economic methods for the evaluation of nutrient depletion 24
4.1 Productivity change approach (PCA) 26
4.2 Replacement cost approach (RCA) 29
4.2.1 Adjustment for fertilizer efficiency 32
4.2.2 Adjustment for nutrient availability 33
4.2.3 Comparing PCA and RCA 34
4.3 Total factor productivity (TFP) 35
4.4 Resource appreciation (1) - hedonic pricing 37
5. Umbrella approaches 38
5.1 Cost-benefit analysis (CBA) 38
5.2 Multi-criteria analysis (MCA) 41

6. Relating nutrient depletion to economic growth – the case of SSA **42**
7. Economic valuation of soil carbon depletion **47**
7.1 Soil carbon depletion 48
7.2 Costing SOM loss through erosion (integrated approach) 52
7.3 Costing different SOM functions 52
7.4 Resource appreciation (2)- farmers' willingness to pay or accept 58
8. Conclusions **59**

Appendix 1 **67**
References **71**

Acronyms and abbreviations

AGDP	Agricultural (share in the) gross domestic product
AWC	Available water capacity
C.A.R.	Central African Republic
CBA	Cost-benefit analysis
CEA	Cost-effectiveness analysis
CEC	Cation exchange capacity
CERES	Crop estimation through resource and environment synthesis (model)
CGIAR	Consultative Group on International Agricultural Research
CIAT	International Center for Tropical Agriculture
CVM	Contingent valuation method
DFID	Department for International Development (UK)
DYNAMITE	Dynamics of Nutrient and Moisture in Tropical Ecosystems (model)
EDI	Economic Development Institute, The World Bank
EIA	Environmental impact assessment
EPIC	Erosion Productivity Impact Calculator (model)
FAO	Food and Agriculture Organization of the United Nations
FAS	Federation of American Scientists
GDP	Gross domestic product
GIS	Geographic information systems
ICRAF	International Centre for Research in Agroforestry
IFDC	International Fertilizer Development Center
IPCC	Intergovernmental Panel on Climate Change
IRR	Internal rate of return
ITFP	Intertemporal total factor productivity (sustainability)
MCA	Multi-criteria analysis
NPV	Net present value
NUREQ	Nutrient Requirements Calculation Procedure (model)
NUTCYC	Nutrient Cycling Modeling Programme (model)
NUTMON	Nutrient Monitoring Programme (model)
NUTRICALC	Nutrient Calculation Programme (model)

PCA	Productivity change approach (productivity loss approach)
PM	Poultry manure
PR	Rock phosphate
RAFA	Regional Office for Africa (Agriculture Department Group) - FAO
RCA	Replacement cost approach
RMD	Resource management domain
SCBA	Social cost-benefit analysis
SCD	Soil carbon depletion
SOM	Soil organic matter
SSA	SubSaharan Africa
SWNM	Soil, Water, and Nutrient Management Programme
TFP	Total factor productivity
TSBF	Tropical Soils, Biology and Fertility Programme
TSFP	Total social factor productivity
WTA	Willingness to accept (compensation)
WTP	Willingness to pay

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Preface

Soil nutrient contents are declining in much, if not most, of the agricultural land in developing countries. In many cases, half of the soil organic matter and its nutrients, found two generations ago, has been used up. This indicates that cultivation and harvesting methods, on balance, are mining the soil, and that we are devouring a natural resource.

While soil scientists and agronomists have been aware of this important land degradation process for some time, it has been largely ignored by resource economics that focus usually on land degradation in general or soil erosion in particular. **As** a result, the consequences of nutrient mining are not appreciated sufficiently.

This edition reveals that appropriate methods exist to illustrate nutrient and SOM depletion in economic terms, and that soil mining expressed thus **is** very significant. On average, as much as 7% of the agricultural gross domestic product of many countries in SubSaharan Africa is due to the consumption or loss of soil nutrients. This is an important statistic for national economies. However, the mining process cannot continue indefinitely as the resources will become exhausted (unlike the consumption of water, that returns again as rain).

We hope that this publication will stimulate many more economic studies on soil nutrient depletion processes, and that it will contribute to more awareness of the consumption of our precious, but limited natural resources.

Frits Penning de Vries
Director of Research

Summary

While there is ample literature on soil nutrient depletion and the benefits of soil organic matter (SOM), there is only sparse reference to the economic assessment of the depletion of soil nutrients and carbon. Most related studies refer to soil degradation in general or soil erosion, as one important process of nutrient depletion. The two major objectives of this publication are (i) to provide an overview about the assessment of nutrient depletion and the major processes of nutrient depletion, and (ii) to provide an overview on different economic valuation approaches for nutrient depletion, including soil carbon depletion, and thus to add to their discussion. We also present an economic assessment of the costs of nutrient depletion in subSaharan Africa (SSA).

Pricing nutrient depletion calls for an interdisciplinary approach. The target should be a compromise between appropriate biophysical assessment and a user-friendly economic valuation method. The "nutrient balance" model proved to be a useful indicator of nutrient depletion and offers a biophysical base for its economic assessment via the replacement cost approach (RCA). Adjustments for fertilizer efficiency, nutrient availability, and possibilities to cost SOM depletion have been suggested. The adjustment of the nutrient balance for nutrient availability affects mostly erosion with relatively low amounts of available nutrients. Our case study shows that countries with high nutrient depletion rates through erosion, such as Malawi, are not automatically countries with high on-site nutrient depletion costs. However, there are severe difficulties with nutrient budget analysis, especially through data aggregation and upscaling. Most reliable are probably farm level assessments, while village (community) level budgets are more adequate to address social and economic resource flows in large parts of rural Africa. Assessments at the country or supra-national level might be of value for policy-makers if used with caution. Of more significance for the farmer are, however, cost assessments at the farm level, which consider the criteria of farmer's decision making as labour prices and

opportunity costs.

In contrast to the RCA, the total factor productivity (TFP) approach emphasizes the unpriced contribution of natural resource stocks and flows. This can be crucial with respect to variations in soil resilience. The productivity change approach (PCA) is favoured for nutrient depletion through erosion as it allows an integrated consideration of all affected soil nutrients and SOM benefits and a direct relation to farmers' income. Methods that assess resource appreciation by the end user, e.g. willingness to pay or the substitute goods approach, can be alternatives or valuable supplements, especially for the economic assessment of SOM functions.

Finally, cost-benefit analysis (CBA) and multi-criteria analysis (MCA) are suggested as frameworks for a more complex impact assessment of nutrient depletion by integrating results from RCA, PCA, TFP, or farmers' assessments. In contrast to CBA and its focus on economic efficiency, MCA allows the integration of nonmonetary costs and benefits, such as a sustainability, thus offering a broader umbrella.

Taking a recent IBSRAM fertilizer retail price survey in SSA as an example, the on-site replacement costs of nutrient mining were calculated on the basis of the nutrient balance model adjusted for nutrient availability. It showed that in certain countries, such as Rwanda, Tanzania, Mozambique, and Niger, nutrient depletion accounts for 12% or more of the agricultural share in GDP, indicating nutrient mining as a significant factor for economic growth. The annual share of the average SSA person engaged in agriculture on the nutrient deficit is about US$32. The case study is based on a range of assumptions but has the advantage of using a uniform estimation method for all countries.

The economic assessment of soil nutrient depletion Analytical issues for framework development

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1. Introduction

Soil fertility depletion is seen as the most important process in the land degradation equation, and as the main biophysical limiting factor for rising per capita food production in the majority of African small farms (Mokwunye, 1996; Sanchez *et al.*, 1997). For the nation *per se*, whose livelihood is dependent mostly on agriculture, unchecked soil fertility decline poses a major threat to economic development. Even in the Sahelian area, it is often the supply of nutrients that limits productivity and not the water supply (Penning de Vries and Djiteye, 1982).

While there is much literature on soil degradation in general and soil erosion in particular, there is very little reference *to* the economics of nutrient depletion, and especially of soil carbon depletion (SCD).

In a joint approach with CIAT and TSBF, IBSRAM took over the initiative to develop a framework for the economic assessment of soil erosion and nutrient depletion. This is part of a DFID-funded initiative within the Soil, Water, and Nutrient Management (SWNM) Programme of the CGIAR. As a first step, a review on the economic assessment of soil erosion was prepared (Enters, 1998a). This study focuses on **nutrient depletion** considering SCD, taking in most cases SSA as an example, as nowhere else is nutrient depletion better demonstrated and of more serious concern in view of food insecurity (Cleaver and Schreiber, 1994; Smaling, 1993; Bojo, 1996).

The major objectives of this study were:

1. To provide an overview of the assessment of nutrient depletion and the major contributors to nutrient depletion.

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2. To provide an overview of different economic valuation approaches to soil nutrient and carbon depletion and to contribute to their discussion.
3. To give an assessment of the economic costs of soil nutrient depletion for **SSA.**

The causes of nutrient depletion as well **as** the different strategies of soil conservation with focus on better nutrient and **SOM** husbandry or nutrient replenishment are not considered and have been described comprehensivelyand summarized elsewhere, for example, by Donovan and Casey (1998) or Sanchez *et al.* (1997).

Box 1: Definitions used in this study

Land degradation is the temporary or permanent reduction of the productive capacity of the land, or of its potential to produce benefits from a particular land use under a specified form of land management. Typical processes enhancing land degradation are, for example, deforestation, overgrazing, or nutrient depletion.

Soil degradation is a broader term for the decline in the capacity of the soil to produce goods of value to humans encompassing the deterioration in physical, chemical, and biological attributes of the soil. Soil degradation **is** a long-term process. Erosion, soil nutrient depletion, soil pollution, salinization, and decline in soil structure are some of the processes contributing to soil degradation.

Nutrient depletion or nutrient mining means net loss of plant nutrients from the soil or production system due to a negative balance between nutrient inputs and outputs. Typical channels of nutrient depletion are nutrient removal through harvest, leaching, denitrification, fire, soil erosion, and runoff.

All three processes are interrelated with socioeconomic and institutional factors (markets, policies, tenure regimes, population growth, etc.).

Adapted from Lal (1994), Steiner (1996), Pieri (1995), and Enters (1998a).

The **structure** of this study basically follows the objectives outlined above. In the following chapter we discuss the nutrient balance as biophysical indicator of nutrient depletion. This is followed by a discussion of socioeconomic considerations as well as different economic concepts, constraints, and assumptions of importance for an economic assessment of nutrient depletion (Chapter 3).

In Chapter **4** we present selected methods for the economic valuation of soil nutrient depletion. This includes well-known approaches but also addresses fields where the economic literature remains very thin, such as cost adjustments for nutrient availability or fertilizer efficiency. The next chapter discusses two umbrella approaches for the methods introduced in Chapter **4.**

In Chapter 6 we present a new assessment of the costs of soil nutrient depletion from the national perspective in SSA.
Chapter 7 has a special focus on the economic valuation of soil carbon and SOM depletion, another field so far little touched by other publications.

In the last chapter, we try to compare the different approaches and methods with regard to an overall framework that considers the different impacts of nutrient and SOM depletion, and combines the different related approaches for their economic assessment.

The study draws from published material but also contains new approaches as well as original data and calculations. To reduce overlap with the IBSRAM study by Enters (1998a), we kept the discussion of the economic assessment of off-site effects short. This field is well covered by Enters. However, off- and on-site effects are considered in the overall framework.

2. The nutrient balance as an indicator of nutrient depletion

In tropical slash-and-burn systems, the common indicator of nutrient depletion is the yield decline after only a few cropping seasons without external inputs. This decline might result more from slash and/or burn residues (ash) becoming depleted of nutrients and less from a declining inherent soil fertility. Decreasing possibilities of shifting cultivation and reduced fallow periods favour soil degradation and call for methodologies for the assessment and monitoring of land quality and its change over time. The classical approach is the analysis and comparison of soil fertility parameters between different treatments, preferably over several seasons or years. However, such experiments are costly to maintain, and it is difficult to select the analytical method which will measure changes in the most significant soil nutrient stocks (cf. Greenland, 1994; Pieri, 1992, 1995). Alternatively, the soil is considered as a black box and the nutrient in- and outflows are analyzed. The assumption is that in the long run, soil fertility is determined mostly by the degree to which nutrient exports (e.g. uptake by crops plus losses due to processes such as leaching, erosion, runoff, volatilization, and denitrification) are balanced by nutrient imports (supplied by, for example, fertilization or dry and wet deposition). The quantification of the different nutrient flows allows calculation of the net difference of the inputs and outputs of nutrients, i.e. *the nutrient balance.* The internal fluxes between pools of different nutrient availability are considered more or less in equilibrium (Smaling and Oenema, 1997; Van der Pol, 1992)[1].

The nutrient balance approach allows besides a quantification and valuation of nutrient depletion, the ranking of the different nutrient output channels, and the modelling and identification of management options influencing them, thus analyzing and preventing nutrient mismanagement. For the economic assessment of soil nutrient depletion, the net nutrient balance offers an important biophysical base. One of the shortcomings of the approach is that it is a relative measure of nutrient stock changes but gives no information on the size of the different stocks of more and less available nutrients in soil. Thus, we need additional data to decide if a certain depletion rate is still tolerable with regard to soil resilience or not.

[1] Soil internal processes, such as the SOM dynamic, differences between available and less available nutrient pools or P fixation, increasingly are integrated in more sophisticated soil (–plant) models (cf. Shepherd and Soule, 1998; Grohs, 1994) and will be discussed again for the economic evaluation **of soil** nutrient depletion (see 4.2.2).

2.1 *The case of subSaharan Africa*

Following the reviews of Pieri (1985, 1989), a milestone was the first large-scale quantification of nutrient depletion per land-use class up to the national and subcontinental scale for nearly all countries of SSA (Stoorvogel and Smaling, 1990). The nutrient balance was described for NPK with five input and five output factors. The Stoorvogel-Smaling report gave birth to a range of additional studies, focusing primarily on farm level estimates of nutrient flows and budgets. Much of this work has been described in a special issue of Agriculture, Ecosystems & Environment under the editorship of Smaling (1998). Other noteworthy works are, for example, by Van der Pol (1992), Poss and Saragoni (1992), Shepherd *et al.* (1996), or Krogh (1997). Recently, IFDC compiled a related data base for the whole of Africa (Henao and Baanante, 1999).

Stoorvogel and Smaling (1990) showed that nutrient losses due to uptake by crops, erosion, leaching, and N volatilization are only partially compensated for by crop residues left on the field, manure and fertilizer application, and atmospheric inputs; thus the annual NPK balances for SSA were negative with minus 22-26 kg N, 6-7 kg P_2O_5, and 18-23 kg K_2O ha^{-1} from 1983–2000 (cf. Stoorvogel *et al.*, 1993). The implication of these figures is, taking N as an example, that on average, soils in SSA must supply 22-26 kg N ha^{-1} y^{-1} to balance the loss, hence leading to a decline of the N stocks. These figures consider soil redistribution via sedimentation inputs in lowlands. However, as they aggregate differently available nutrient pools, a wide variety of land-use systems, crops, and agro-ecological zones in each country, they are certainly only approximations of the problem.

Box 2: Soils in SSA – an extreme example?

Tropical Africa is not at a disadvantage in terms of climate or soil when compared with tropical regions of Latin America and Asia. Regardless of current nutrient mining, only 20% of African soils suffer from inherent low nutrient reserves as compared to 43% of the soils in Latin America. On the other hand, the available nutrient pool is more limited in Africa with 13% of all soils being law in CEC. In Latin America the figure is only 5% (Sanchez and Logan, 1992). Estimates of the area of African oxidic soils with high P fixation vary between 205 M ha or 7% (Sanchez and Logan, 1992) and 530 M ha or 18% (Sanchez *et al.*, 1997).

According to the R factor representing the ratio between cropping and fallow periods[2], the nutrient balance that considers nutrient inputs during fallow periods allows us to determine an overall **R** threshold for natural (fallow) N replenishment of about 0.2 at the current level of fertilizer and manure input (Drechsel and Penning de Vries, in press). In other words, for soil management to be sustainable at the current level of inputs, only 20% of the arable land should be cultivated annually This situation is uncommon in SSA today. The average R value **is** estimated to be about 0.60 in the year 2000. This means that most farming systems are mining nutrients as they cannot afford the required fallow periods.

2.2 Modelling and integration of spatial scales

Different authors have elaborated on nutrient balance calculations into decision support models that allow monitoring of the effects of changing land use and suggestions of interventions to improve the nutrient balance (cf. Box 3). NUTMON (Smaling and Fresco, 1993) is known widely and has proved to be an adaptable instrument (De Jager

[2] R = years of cultivation/(years of cultivation + fallow years)

et al., 1998ab;4 Van den Bosch *et al.*, 1998; Vlaming *et al.*, 1997). Closely related are the nutrient requirement calculation procedures NUREQ (Van Duivenbooden, 1992) and NUTRICALC (De Barros *et al.*, 1995).

Such nutrient balance models facilitate data aggregation and generalization from the field to higher levels. This might be the catchment area in erosion studies or the national level to analyze the impact of nutrient depletion on national economics. Thus, upscaling gives policy-makers, for example, an impression of the larger picture. Case studies from **SSA** and Central America showed that the integration of spatial scales in models like NUTMON is possible, but constrained by limited data availability and by scale-specific variability (Stoorvogel and Smaling, 1998). Scales used in nutrient balance studies included, for instance:

- Experimental plot (a part of a cropping system).
- Field (a cropping system).
- Farm (several cropping systems).
- District (certain land-use system(s).
- Climatic zone (certain land-use systems with similar production potential).
- Country or region (different land-use systems).
- Continent (large variety of land-use systems).

However, it is essential to be aware of the limitations inherent in data aggregation (Hashim *et al.*, 1998; Scoones and Toulmin, 1998), which will be discussed in the following section.

Box 3: Nutrient balance models

As input and output determinants cannot be quantified equally well, the **NUTMON** model can use primary data, estimates, and assumptions. The determinants are mostly scale-neutral and can be used to monitor nutrient balances at the farm, regional, national, and supra-national level. This is essential since the hierarchical levels interact. NUTMON can aid the development of land-use policies aimed at balanced nutrient use in (so far only) African land-use systems. It can help determine the effects of current and alternative land use on productivity and sustainability, however, without addressing long-term effects (Smaling and Fresco, **1993).** A comparable time-static nutrient budget model with stronger emphasis on agroforestry was used by ICRAF (Shepherd *et al.*, **1996).** A dynamic and extended version of this model was presented by Shepherd and Soule **(1998).** It allows assessment of the long-term impact of existing soil management strategies, on farm productivity, profitability, and sustainability. The model, which runs in time units of one year, links soil management practices, nutrient availability, plant and livestock productivity, and farm economics at multiple scales.

NUREQ is a nutrient requirement calculation procedure that calculates annual fertilizer/manure or fallow period requirements in a target-oriented way, i.e. on the basis of exogenously determined target yields. Like NUTMON, the calculations are based on the dynamics of nutrients within the production system, i.e. the nutrient in- and output fluxes.

NUTRICALC is a software programme for tree plantations that takes into consideration site index, rotation age, soil properties, effective soil depth, and efficiency of nutrient utilization for estimating nutrient balance and fertilizer recommendations for fast-growing eucalypts [Eucalyptus spp.] in the tropics. Additionally, stand biomass and nutrient content are required if the forest is to be managed by coppicing or replaced. The programme generates three kinds of reports: Technical, which records all the input information and the estimated nutrient balance and recommendations; Operational, which contains the recommended fertilizer treatment; and Economic, which states what fraction of the income will be spent on fertilizer.

2.3 Limitations of the approach

Depending on the ease with which the component inputs and outputs can be assessed, most of the studies mentioned above use semiquantitative estimations (transfer functions, regressions) and assumptions on the basis of literature reviews and expert assessments, besides directly measured in- and output data. In fact, it is rare for all factors to be considered adequately in the same experimental system or study area; this makes assessment of their relative significance a difficult and complex task (Syers, 1996; Hashim *et al.*, 1998).

Scoones and Toulmin (1998) highlight some of the difficulties with nutrient budget analyses, including potential problems with a snapshot approach when trying to understand longer-term dynamic processes; the danger of extrapolating nonlinear relationships to wider scales (see below) from limited site-specific data sets; the challenges of understanding diversity, complexity and uncertainty within smallholder farming systems; and the importance of insights into the many socioeconomic and institutional factors that influence decision making at the farm level and so mediate the processes of environmental change. The authors emphasize caution particularly in view of aggregate studies, problem generalization, and related inappropriate blueprint solutions on local settings, such as large-scale fertilizer programmes. But they also emphasize the advantage of the approach as a tool for participatory research and simple devices to encourage debate and dialogue among farmers, technical scientists and policy actors in a participatory process of negotiating interventions or policies for tackling issues of agricultural sustainability. In fact, nutrient balance studies have left their "ivory tower of science". Defoer *et al.* (1998, 1999) developed a tool kit for participatory on-farm research that allows the visualization of resource and nutrient flows. The resulting diagrams assist farmers in analyzing nutrient budgets and their soil fertility strategies, and in planning step-wise improvements.

Upscaling might multiply inaccuracy deriving from differently assessed data or a nonrepresentative basic scale. Average values, especially at larger scales, will certainly mask variations in depletion rates: There can be nutrient depletion for certain cropping or farming systems or parts of the farm (eroded upper slope) and sustainable cropping with positive balances in other systems in the same area (or lower slope). Two examples are given:

a. Farm level

Spatial variability is a common pillar of indigenous nutrient conservation as examples from East and West Africa show. Farmers apply the limited amounts of (organic) inputs preferably on fields and gardens close to the homestead where the crops are best protected against thieves and transportation distances are short. Here the productivity remains at a relatively high level and serves the most valuable (cash) crops (Nwafor, 1979; Prudencio, 1993; Quansah *et al.*, 1999). In contrast to other fields, the nutrient balance is usually positive on these plots (Smaling and Braun, 1996).

b. Village level

Straight upscaling from the plot or farm level to the district or region may overlook significant horizontal or time-depending nutrient flows and their impact on the nutrient balance, such as

- Crop marketing structures and related nutrient flows.
- Off-farm nutrient input via livestock.
- Rotation between fields/fallows of different fertility.
- High input plots close to the compound.
- Sedimentation of eroded soil on the next field or lower slope.
- Crop storage for own consumption.

In a case study from Burkina Faso, for example, the flows of N and P for both single fields and a village territory were assessed (Krogh, 1997). The results suggest that N and P are lost from fields, but with boundaries at the village territory, the balances show a negligible output of N and an input of P to the "village production system". The combination of the two different spatial scales suggested that millet cultivation is more sustainable than generally thought. In another example from Kenya, Vlaming *et al.* (1997) showed that subsistence farmers are able to compensate for the losses made by harvested products at the farm level through manure derived from grazing off farm, i.e. on communal pastures. A similar input was considered in the Burkina study. Nutrient flows of farming systems with a livestock component are therefore significantly more difficult to assess than systems without livestock (Smaling and Oenema, 1997). But the results indicate that the farming community of the larger village area is a favourable hierarchical level for measuring agricultural sustainability in small-scale farming of SSA (Izac and Swift, 1994; Barbier, 1998).

In summary, several questions of scales and hierarchies still have to be resolved, especially how to scale up biophysical data to the level at which public policy is formulated without losing the integrity and reliability of the data (Dumanski *et al.*, 1998; Syers, 1996). Henao and Baanante (1999) suggest a geo-referenced approach linking data base modelling and GIS. Often it is desirable to consider the dynamics of nutrient flows, i.e. temporal scales need to be defined (Smaling and Oenema, 1997). Their impact on the nutrient balance can be significant (Brand and Pfund, 1998). Dumanski and Craswell (1998) emphasized the advantages of the resource management domain (RMD) concept as a framework for the comparison of scale-related (spatial and temporal) research results from different regions.

2.4 *Relative importance of the different depletion processes*

Taking a closer look at the different processes contributing to nutrient depletion, using the example of SSA, we see that two output channels are predominant and control the final balance at different scales, regions, and zones (Figure 1). These are erosion as well as crop plus residue removal, which constitute about 70% of all N losses, nearly 90% of all K losses, and 100% of the P losses.

In the case of N, erosion contributes on average 37% to N loss; crop harvest and residue removal 27 and 8%, respectively; gaseous losses 19%; and leaching 9%. In the case of P, erosion contributes 43% to depletion, harvest (without residues) 42%; and residue removal 15%, while leaching is negligible. With respect to K, the high content in crop residues (especially of cereals) is remarkable. Erosion contributes 39% to the average K loss, crop harvest and residue removal each with about 24%, and leaching up to 12%. The last figure might be overestimated (Pieri, 1992).

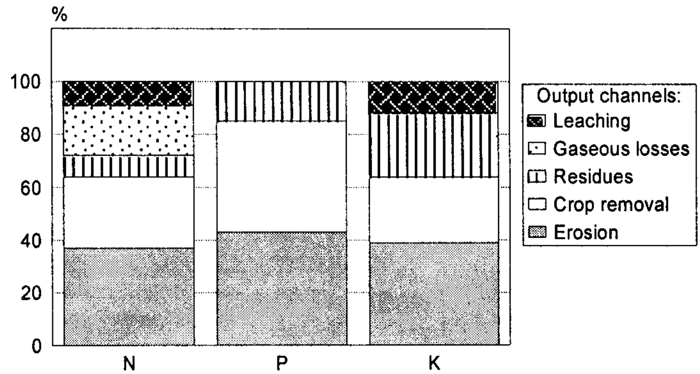

Figure 1. Composition of NPK outputs on rainfed soils of SSA. The figure summarizes all output data provided by Stoorvogel and Smaling (1990) per country and the different FAO land/water classes for rainfed land.

In comparison with erosion, nutrient leaching appears to be a minor contributor to N and K depletion. Only in 6% of all cases, mostly from humid SSA with very low erosion rates, are N and K losses through leaching of similar or higher importance than through erosion. Leaching losses certainly increase with the amount of fertilizer or (green) manure applied and can be more significant for other nutrients than NPK[3]. Substantial leaching losses of Mg and Ca, for example, mobilized by nitrate, are described for different regions of SSA (Pieri, 1985, 1992; Poss and Saragoni, 1992).

[3] There is scant knowledge on nutrients other than NPK in SSA (Donovan and Casey, 1998), and strategies of soil nutrient replenishment might backfire if they fail to consider the *de facto* complex soil and plant nutrient balance.

Box 4: Nutrient depletion through plantation forestry

Nutrient mining is not only a major concern of agricultural soils, but also a serious challenge for **tropical forestry**. Although the loss of inorganic nutrients is considered less in forestry because wood has a relatively low nutrient content, and harvests occur less frequently (Nykvist *et al.*, 1994), a simple data comparison indicates less obvious differences (Table 1).

Table 1. Nutrient depletion (kg ha^{-1} y^{-1}) in tropical agriculture vs. tropical forestry.

N	P	K	Ca	Mg
Pine plantation (bole harvest plus steady-state leaching per (rotation) year)				
n.a.	3-4 kg P	10 kg K	21 kg Ca	8-11 kg Mg
Teak plantation (bole harvest plus steady-state leaching per (rotation) year)				
n.a.	6 kg P	12 kg K	43-64 kg Ca	9 kg Mg
Average annual nutrient loss through harvest and leaching on agricultural land in SSA				
14 kg N	2-3 kg P	12 kg K	2-30 kg Ca	5-13 kg Mg

Data adapted from Bruijnzeel (1992); Stoorvogel and Smaling (1990); and Pieri (1992)

While the nutrient balance of natural (undisturbed) forests seems to be in equilibrium (Proctor, 1987), forest clearing, burning, and the establishment of fast growing tree plantations with short rotation periods (e.g. *Eucalyptus* sp., *Pinus* sp., *Acacia* sp.) results in severe nutrient losses (Chijioke, 1980). The available data indicate poor sustainability of most tree plantations already in the second rotation due to nutrient export through harvesting (Zech and Drechsel, 1998). Affected nutrients are often Ca, K, or Mg. Nutrient balances were analyzed in view of the best nutrient saving rotation period of forest plantations (e.g. Hase and Fölster, 1983; De Barros *et al.*, 1995; see also Box 3) but also with respect to the hazards of continued large-scale deforestation of primary forests (Salati and Vose, 1984). Plantation forestry only appears to be sustainable under conditions of good husbandry, but not where wasteful and damaging practices are permitted (Evans, 1999).

It is worthwhile mentioning that if we calculate scenarios without erosion, runoff, and leaching, in upland SSA we still get a negative N and K balance through the amount of nutrients lost with the harvested crop and its residues. The data stress that although soil conservation is crucial, it can only reduce the speed of nutrient depletion. This corresponds with empirical evidence: Although soil conservation measures are usually very effective in reducing soil erosion, a yield impact is often negligible if no other inputs are provided simultaneously (Grohs, 1994; Steiner and Drechsel, 1998; Herweg and Ludi, 1999).

With the exception of erosion, the different in- and outputs mostly concern available nutrients. The different nature of nutrients lost through erosion requires special attention with respect to the economic assessment of nutrient depletion (cf. 4.2.2).

3. Towards an economic assessment of nutrient depletion

For the economic appraisal of the extent and impact of soil fertility depletion, an appropriate assessment framework and tools should be available. Both will be challenged by a variety of concepts and assumptions, scales and time frames, reversible and irreversible impacts, tangible and intangible benefits, etc. The following chapters will describe briefly some of the factors, constraints, and concepts to be considered in the valuation process.

3.1 *Nutrient depletion and its socioeconomic environment*

The extent of issues to be dealt with when assessing the economic impact of nutrient depletion requires a broad, multidisciplinary/ interdisciplinary approach and calls for understanding of the interactions of nutrient depletion with a farmer's soil management and his/her decision making. It then becomes evident that besides *physical factors* we have to consider, for the economic assessment of nutrient depletion, a range of interactions with the *socioeconomic environment* to understand the driving forces behind it (Figure 2).

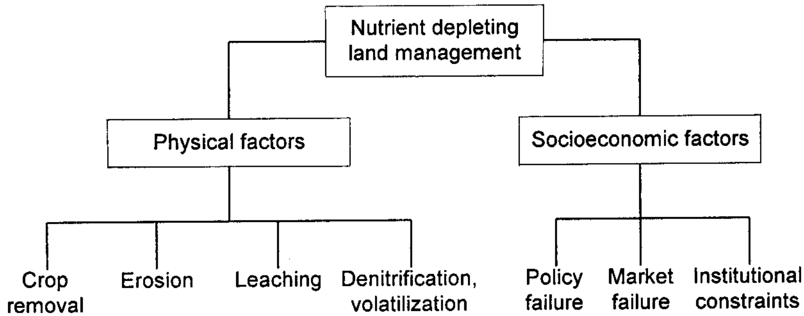

Figure 2. Nutrient depletion as a function of physical and socioeconomic factors.

In the introduction, we defined nutrient depletion as a result of different biophysical processes interrelated with socioeconomic factors such as market and policy failures as well as institutional constraints (Box 1). It is sometimes debated to what extent the causes of nutrient depletion are man-made (i.e. physically, socially, economically) and to what extent natural factors are the culprits (Bojö, 1991). However, what matters from an economic point of view are the costs of stopping or reversing nutrient depletion, no matter what caused the situation. From an economic point of view, a certain decline of natural soil fertility under agriculture is not considered to be necessarily bad (Bishop, 1992). The assertion that land-use practices are wrong in view of nutrient management must be based on evidence of failure in relevant *markets, policies, and/or institutions* (cf. Bojö, 1991; Bishop, 1992; Scherr, 1999). The argument is that failures such as low price stability, no access to credit, missing subsidies or weak research-extension linkages, lead farmers to deplete land assets at an inefficient rate, which may be too fast (for soil resilience) or too slow compared to some socioeconomic "optimal" course of soil exploitation (Bishop, 1992). Other, partly related factors include inadequate knowledge, resource constraints, inability to bear market risk, insecurity of land use, and technical limitations (Donovan and Casey, 1998).

Assessment constraints

Assessments of the economic impacts of soil degradation or nutrient depletion are generally hard to come by. There are several reasons:

1. First, nutrient depletion and its interrelations with society, are located in the developing world, whereas the theory and practice of economic valuation have been developed and applied mainly in the developed world with different market conditions (Izac, 1994; Pearce and Moran, 1994).
2. Secondly, the qualitative and nonmonetary costs of soil degradation as well as the benefits of soil conservation are difficult to quantify, and often of long-term value or impact. This not only concerns social aspects. Even a unit value of nutrients may vary considerably depending on, for example, their biochemical availability, their impact on plant production, and financial returns as well as in view of the remaining stock of nutrients in the soil. Different soils have different tolerance levels with respect to nutrient stocks and resilience, and irreversible damage is possible.

The real assessment problem is that nutrient depletion has a far reaching impact that extends beyond the soil and farming household into community, regional, and national scales; it concerns the environment (e.g. decreased above- and belowground biodiversity) and the agricultural sector (reduced yields, income, and food security). Nutrient depletion can inflict on-site costs (e.g. more labour input to balance decreasing soil fertility and on-farm biomass availability) and can be linked to off-site costs (via erosion, sedimentation etc.) up to reduced national economic growth and additional CO_2 emissions to the atmosphere from decreasing soil carbon stocks (Sanchez *et al.*, 1997). Other consequences of depletion are: decreased food security through lower production and resulting higher food prices, lower employment, increased government expenditures on health, more famine relief, and reduced government revenue due to less taxes collected on agricultural goods. A comprehensive assessment of the impact of soil degradation on food security, that can be applied to nutrient depletion, was recently published by Scherr (1999).

Box 5: Subsidies – no general solution

By 1994, fertilizer subsidies were either reduced or eliminated in 16 out of 29 ***SSA*** countries. Subsidy removal is believed to have led to reductions in fertilizer consumption in Ghana, Zambia, Tanzania, and Malawi, for example though empirical evidence is low (Donovan and Casey, 1998). In Ghana, for instance, the decline from 65 000 mt in 1989 to 11 600 mt in 1994 was accompanied by an increase of the nominal retail price from 295 cedis to 13 100 cedis for 50 kg of ammonia sulphate. The sharp price increase is attributed partly *to* devaluation, partly to subsidy withdrawal, and partly to general inflation. Whether subsidies are needed or not has to be examined on a case-by-case study. Subsidy removal can result in decreased as well as increased fertilizer demand as there are many other factors influencing fertilizer profitability. There are strong reasons for suspecting that pricing reforms will not affect soil conservation dramatically (Barrett, 1991). Structural adjustment programmes, even though they aim at supporting the agricultural sector, often have a negative impact on soil fertility management. Studies in Tanzania and Zambia indicated that the abolition of fertilizer subsidies led to less intensive agricultural production. Farmers returned to soil mining and expanded cultivated land with all the accompanying detrimental effects on the environment. It is therefore doubtful whether liberalization of agricultural markets alone is the answer to the crisis of agriculture (Pieri and Steiner, 1997).

3.2 Scales of economic assessment

Parallel to the efforts of soil scientists to upscale data on nutrient depletion, economists also try to address different spatial and temporal scales and levels, such as the "farmer", or interactions with the community, or the assessment of the costs for the entire national economy. While we emphasized in section 3.2 the limits of data transfer from one scale to another, we also have to stress the need for sustainability assessments at different scales. What is deemed relevant in a given situation will vary according to the different priorities and interests of different scale-related stakeholder groups, reflecting the risks and opportunities they face. Policy-makers require ‘easy to understand’ indicators to capture at each scale ecological, economic, and social sustainability. Analysis of these indicators must take place in connection with other indicators and has to include a time or dynamic factor to facilitate indication of trends over time and monitoring activities. Thus, the choice of the scale level depends on the objective of the analysis.

At the “farmer” level, economists try to assess the benefits and costs that accrue directly to the farmer and his/her decision making. In all likelihood, these farmers will acknowledge only the monetary benefits of increased yields and the nonmonetary benefit of decreased risks of yield fluctuations. In addition, labour input and opportunity costs will significantly determine their profitability assessment (cf. Izac, 1994; Kunze *et al.*, 1997). As subsistence-oriented farmers are often uncertain about their ‘survival’ in farming from one year to the next, their ‘planning horizons’ for land-use decisions are relatively short (e.g. 2-3 years) and constrained by limited access to land (due to shifting cultivation and tenure agreement). This short horizon is a prerequisite for them to stay in business in the short term to be able to survive in the long term (Izac, 1994). It is therefore likely that, even if they were aware of the medium- and long-term nonmonetary benefits of soil management, most farmers would discount these benefits because they occur over a period of time of little relevance to their immediate needs or address a field which will not be theirs in the next year. The benefits would go to the land owner. Especially in villages close to urban centres with increasing land pressure and insecurity of land tenure, farmers are increasingly changing to short duration crops and rental periods as the land may be used for development in the near future.

The second level tries to give more weight to the farmers’ environment. Despite the limited time frame, farmers integrate a wide range of ecological and socioeconomic parameters belonging to levels often higher than the farming system, in their decisions to manage their lands in a given way. The decisions made at the farming system scale have repercussions at the same scale, as well as at lower and higher scales in the hierarchy. These are mediated through various economic, social, and biological processes such as nutrient cycling, family relations and exchange arrangements, as well as market mechanisms. Because these processes transcend farm boundaries, it is helpful to establish a distinction between the economic processes that occur at the farming system scale and those that are characteristic for the village or regional, national, or global level (cf. Izac, 1994).

The third level concerns the assessment of costs and benefits for the society in general within a country as it contributes to agricultural sustainability and food self-sufficiency. Generally the macro-economic assessments have two objectives: Firstly, to put a value on a natural resource that is "used up" through agricultural production by applying a "national resources accounting" approach to quantify the costs of nutrient depletion or soil degradation to the economy. Secondly, to compare the costs of nutrient depletion to the costs of conservation technologies and to assist decision-makers who are inadequately weighing the cost and benefits of soil conservation policies (cf. Grohs, 1994).

3.3 Concepts and considerations

Physical data on nutrient depletion are of little use to decision-makers unless they are transformed into units also used for the assessment of the cost of soil conservation. There are many different ways of expressing "cost of nutrient depletion." This depends not only on the method (e.g. replacement cost approach) but also on the concepts and assumptions. Bojo (1996) differentiated these along different dimensions; some of them are discussed briefly below.

Financial versus economic cost: The financial analysis is made from an individual point of view, while economic analysis takes a societal point of view. Financial and economic values are similar if there are no policy failures and no environmental or social impacts of using resources in producing goods and services (Bojö, 1996). If policies such as minimum prices or price ceilings, quotas or subsidies for production, imports or exports, speculation on market prices among others, are not rectified by macro-economic or sector adjustments, prices have to be approximated for what they really would be if the right policies were in place (Table 2).

Table 2. Financial vs. economic analysis.

	Financial analysis	Economic analysis
Point of view	Net returns to equity capital or to private group or individual	Net returns to society
Purposes	Indication of incentive to adopt or implement	Determines if government investment is justified on economic efficiency basis
Prices	Market or administered (may assume that markets are perfect or that administered prices have compensated for imperfections)	May require "shadow prices" (e.g., monopoly in markets, external effects, absence of markets)
Taxes	Cost of production	Part of total societal benefits
Subsidies	Source of revenue	Part of total societal cost
Loans	Increase capital resources available	A transfer payment; transfers a claim to resource flow
Interest or loan repayment	A financial cost; decreases capital resources available	A transfer payment
Discount rate	Marginal cost of money; market borrowing rate	Opportunity cost of capital; social time preference rate.
Income distribution	Can be measured re: net returns to individual factors of production such as land, labour, and capital. analysis or as weighted efficiency analysis.	Is not considered in economic efficiency analysis. Can be done separately

Source: EDI (1998), modified.

On-site versus off-site costs: On-site costs refer to the direct effects of nutrient depletion on the quality of the land resource itself, often expressed in terms of reduced agricultural productivity. Some off-site costs are related directly to the depletion of nutrients (e.g. fertilizer runoff and water eutrophication; cf. Box 6) but the majority are related to soil erosion and silt or agro-chemical products washed into streams or leached into groundwater. Such externalities arising in a process of production or consumption are not reflected in market prices or in farmers' decision making, but they are an integral part of the economic contribution made by agriculture (Bishop, 1992). Most studies focus on on-site costs for the assessment of off-site costs related to erosion; see for example, Enters (1998a) and Grohs (1994).

Product scope: All studies on the cost assessment issue have their limitations. They usually focus only on a few nutrients and crops, sometimes even ignore nutrient flows related to livestock, and only consider certain processes of land degradation. Most of the studies reviewed by Bojö (1996) focus on the major food crops in the country. Marginal and export crops, which are often perennial tree crops and less subject to erosion or nutrient depletion, are not included generally. From studies carried out by De Jager *et al.* (1998b), for example, we know that cash crops often show lower nutrient mining levels than food crops or even positive nutrient budgets. Obviously, the extent of crop inclusion will affect the level of damage estimated.

Absolute versus relative costs: Comparing the costs of nutrient depletion between, for instance, Rwanda and Nigeria, will result in higher absolute figures for the larger country, while costs related to the area (hectare), per capita, or the agricultural gross domestic product (AGDP) will give quite a different picture (cf. Appendix 1).

Consideration of nutrient stocks: Comparing the costs of certain nutrient losses gives only a relative estimate but no indication about the importance with respect to the nutrient stocks and absolute resource depletion.

Discounted versus nondiscounted costs: Discounting is the usual method used to compare costs and benefits that occur at different points in time. There are two fundamental justifications for discounting (Nunan and Bishop, 1999): (i) *time preference* or the fact that most people prefer to receive benefits as soon as possible and to postpone costs; and (ii) the *opportunity cost of capital*, which reflects the scarcity value of investment capital (savings) and returns to alternative investments. The cost of capital is measured normally by the market *rate of interest* or the cost of funds to the decision-making agency. Pure time preference is not easily measured, but it is implicit in people's behaviour. With high rates of interest, short-term investments are relatively more profitable than long-term investments. On the other hand, a decrease in the rate of interest will tend to cause people to invest in enterprises with longer production periods. For long-term environmental impact studies it is recommended to use the real discount rate instead of a nominal discount rate. The economic rationale for discounting and its implications for environmental management in developing countries has been discussed extensively in the literature (Markandya and Pearce, 1988; Enters, 1998a; Pearce *et al.*, 1990; Winter-Nelson, 1996; Rabl, 1996; Pearce and Turner, 1990; Hanley and Spash, 1993).

The discussion is animated as conventional discounting procedures are alleged to discriminate against future generations and environmental quality and resource conservation as a consequence of:

- reducing the negative impacts to society of long-term effects, such as soil degradation;
- discriminating against investments with long gestation periods, such as soil conservation;
- accelerating the depletion of natural resources; the higher the discount rate the greater the rate of extraction of nonrenewable resources.

There are essentially two ways around this problem (Nunan and Bishop, 1999): One is to adopt a lower, social rate of discount where environmental concerns are paramount, the other way is to impose a *sustainability criterion* on projects with environmental impacts (Pearce and Turner, 1990). Kotschi *et al.* (1991), for example, emphasize an ecological discount rate of zero for natural resources and their benefits.

The authors argue that there is no reason to decrease the value of natural resources with time, if they are not marketable if any benefits are used for re-investment. With a discount rate of zero, the discount factor for future revenues/values is constant and for each point in time remains one (cf. Hueting, 1991). However, there is no unique relationship between high discount rate and environmental deterioration and a lowered discount rate could be counterproductive (Pearce and Turner, 1990).

Short-term vs. *long-term costs:* The irreversible destruction of soil productivity is of special relevance for an economic evaluation. An irreversibility exists, if the original state of a resource can only be achieved at infinitely high or prohibitive costs, or if it would take an unacceptable time span. While lost nutrients can be replaced, usually through fertilizer, certain functions of SOM may be nonrenewable in a given geographical context and time frame of, for example, one human generation (cf. section 6.3). Future losses in income can be considered through discounting, using a real social discount rate (see above). Other economic concepts that incorporate the risk of irreversible destruction of soil productivity are *option value* and *safe minimum standards.* Both concepts are discussed by Pearce and Turner (1990) and Grohs (1994).

3.4 *Criteria for method selection*

All the valuation techniques outlined below have strengths and weaknesses and the decision on which to use for a particular application requires experience and judgment on the part of the analyst. Which evaluation approach and method is chosen, for its relevance to a specific decision-making process, depends on various methodological and practical considerations.

For the selection of format, scope, and methodology of the assessment, the decision-makers and the assessment team will have to consider the following questions (cf. De Graaff, 1996, modified):

- *The objectives:* Why do the users need the assessment results? Are there many different users, at different scales (see above) with different objectives? Which method fits into the current decision-making process and its institution? How could the results be made comprehensive and comprehensible to the users and which approach could be followed that relates to their way of thinking?

- The type of criteria that play a role in the evaluation and that are derived from the objectives: **Is** the set of criteria complete, and does it not lead to double counting? Can the method come up with results that are relevant for these criteria and what is the credibility of these results?
- Method sensitivity: Can the evaluation method produce results that are objective, consistent and allow for a clear-cut comparison between the alternatives, not in any way affected by the choice of method?
- Cost *effectiveness*: What (amount of) data does a method require, how reliable are the results the method can produce, and do the analytical costs match the value of the information?
- Regarding budget, time, manpower and *data* availability constraints: What should be the scope and amount of detail of the analysis, given these constraints? Should a simple or a more sophisticated method be applied?

Assessment criteria, whether monetary or nonmonetary, could focus not only on attainability, but also on certain minimum requirements such as efficiency, equity, and ecological sustainability.

4. Economic methods for the valuation of nutrient depletion

The negative consequences of nutrient depletion under agriculture are recognized widely, but until recently few attempts have been made to estimate the magnitude of the costs involved. Given the complex spectrum of causative factors of nutrient and carbon depletion and their impacts, how can this be assessed economically? A variety of methods have been developed and discussed to internalize environmental issues in traditional economic assessments. For nutrient mining, however, two relatively simple approaches, the replacement cost approach (RCA) and productivity change approach (PCA), most generally are used. Both can be integrated into cost-benefit analyses and be used for on- as well as off-site effects (cf. Grohs, 1994; Enters, 1998a; Bojö, 1996).

Methods that require extensive data or complicated experimental techniques have limited applications, especially in developing countries where sophisticated data are seldom available. Here simple approaches in valuing environmental effects might find more acknowledgment. In the following sections, we show examples of economic approaches that are based either on calculating the real or "imaginary" costs of nutrient or carbon depletion, or by assessing their subjective value to population.

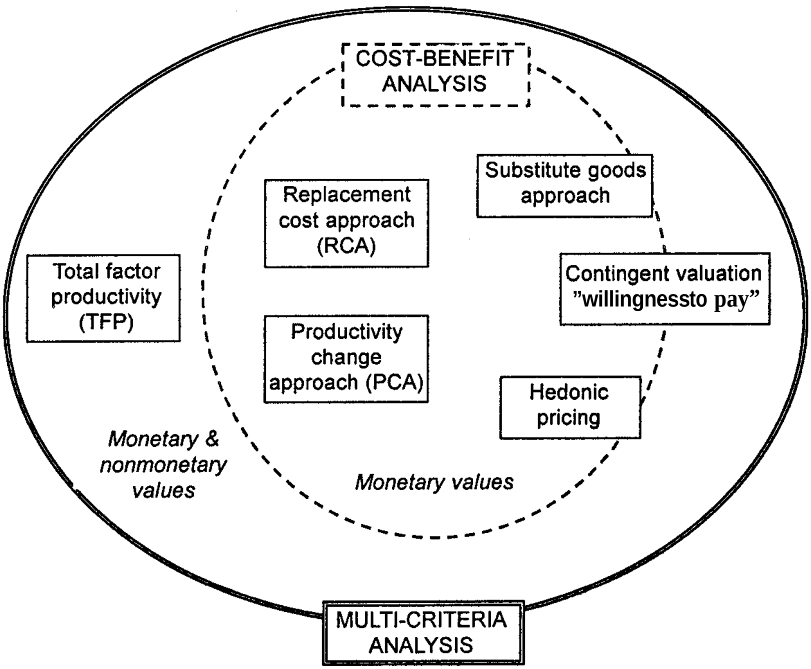

Figure 3. Methods for the economic assessment of nutrient depletion (overview).

These include well-known approaches, such as the PCA, the RCA as well as total factor productivity (TFP) and different surrogate market approaches, which also address fields where the economic literature remains very thin, such as cost adjustments for nutrient availability or fertilizer efficiency as well as the economic assessment of SOM depletion (in a separate chapter).

Finally, the cost-benefit analysis (CBA) and the multi-criteria analysis (MCA) are presented as two umbrella approaches that offer frameworks for a more complex impact assessment of nutrient depletion by integrating results from RCA, PCA, TFP etc. while considering criteria of farmers' decision making. While CBA requires monetary values, MCA allows the integration of nonmonetary costs and benefits (Figure 3).

4.1 *Productivity change approach (PCA)*

One of the impacts associated with nutrient depletion pertains to productivity losses and hence is valued through the ***change in (soil) productivity*** or ***productivity change approach.*** The method is often used to estimate the indirect use value of ecological functions of natural resources, through their contribution to market activities. It involves a two-step procedure. Firstly, the physical effects of changes in the environment on productive activity are determined. The second step consists of valuing the resulting changes in production, usually using market prices. In this case, the PCA takes the reduction in the capitalized net annual income stream gained through agricultural production (i.e. loss of income) as a substitute for the costs of nutrient depletion.

> The ***change* of *productivity*** technique is the most frequently used approach in environmental economics. The technique values change in the supply of a good or service caused by, for example, erosion damage with conventional market prices based on the actual behaviour of market participants. Two ways of applying the change of productivity techniques to assess the costs of nutrient depletion are possible. The potential yield loss due to soil mining can be first estimated and then evaluated by comparing the actual yield on a depleted soil to the potential

yield on a conserved soil. The other possibility is to compare the increased production from actually conserved land with the production on nonconserved land to identify the actual yield loss attributed to soil mining (Grohs, 1994).

A key requirement of this approach is detailed information on the physical relationship between the environmental regulatory function and the economic activity it supports. In addition, market conditions and policy distortions affecting production decisions need to be taken into account (Nunan and Bishop, 1999).

PCA studies often focus on water-induced erosion, but with a different degree of sophistication. Bojt) (1996) found five different approaches that might be used alone or in combination. In part they require the (experimental) assessment of the amount of soil eroded:

(i) expert judgment
(ii) general soil loss - yield decline functions
(iii) directly estimated soil loss - yield decline functions
(iv) depth **loss** - yield decline models
(v) plant growth models

The principle is that processes, like erosion, have at least in theory a distinct impact on crop yields. This impact can be assessed through general, site- and/or crop-specific regression functions or more complex computer-based models, which may even combine different soil - plant models (cf. Bishop and Allen, 1989; Lal, 1995; Bojö, 1996). The **PCA** has the advantage that it does not care about different nutrients or nutrient fractions. What counts is the yield as a function of all (on-site lost or off-site added) soil "services" (cf. Box 6).

Box 6: Nutrient impact on downstream soil and water quality

The **change in productivity approach** can be used to assess, for example, the economic benefits of lowland rice farmers who take advantage of nutrients and organic matter generated by erosion. The **PCA** can also be used to assess the off-site costs of water pollution through nutrient runoff after excessive application of, for example, mineral fertilizer or poultry manure. The level of nutrient export from the upland watershed may be related, for example, to fisheries' production of a downstream reservoir. The initial status of the reservoir determines the effects of increased levels of nutrient loading. If the reservoir is nutrient-poor, increased nutrient loading may increase fisheries' production. Eventually, additional nutrient input will reduce fisheries' production. If nutrient loading is allowed to proceed a point may be reached where irreversible effects occur; the reservoir is so eutrophic that fish can no longer exist and the system cannot recover without some major rehabilitation efforts. To evaluate the effects of a project in this example, the effects of nutrient export would need to be known, along with the present status of the reservoir (Gregersen ***et** al.*, 1987). Another approach would be to use the **contingent valuation method** (cf. section **7.4)** to estimate welfare losses via people's **willingness to pay** for cleaner water (Hanley and Spash, **1993).**

It is of course easier[4] to find a function between crop yield and one easily measurable nutrient output (e.g. erosion) than simultaneously for all different in- and output processes that are summarized in the nutrient balance. The latter is only possible with multivariate models (cf. Box *7).* If the yield loss is estimated, local market prices can be used to determine the financial implications for the farmers, while world market prices can be used to determine the economic impact for the

[4] In fact, this is not easy. Long-term experiments are scarce and the results are affected strongly by site specifics, especially rainfall variability. **Lal** (1995) listed some critical assumptions of erosion-productivity relationships.

society at the national level. PCA has been used extensively in both developed and developing regions to estimate the impacts of deforestation, erosion, etc. **A** weakness of the approach is that it does not consider the stock of arable soil or (potentially) available nutrients and thus soil resilience.

4.2 *Replacement cost approach (RCA)*

In comparison with the PCA, the replacement cost approach (RCA) does not focus on changed or lost income (crop yields) but the additional "input" required to compensate for lost soil nutrients (usually ignoring interactions with SOM, soil structure, etc.). For convenience, this input is usually mineral fertilizer. However, labour costs could also be useful, for example, in biomass transfer (cut-and-carry) systems. The method allows one to assign monetary value to the depleted nutrients based on the cost of purchasing an equivalent amount of chemical fertilizer[5]. The approach benefits from the fact that for at least some common nutrients *direct market prices* are available.

> The **RCA** uses the costs that would have been incurred to replace a damaged asset. Although the technique uses market prices the valuation is based on potential behaviour. The replacement cost does not measure the benefits of avoiding the damage in the first place and can therefore be higher or lower than the damage costs. The RCA has been applied to assess the costs of soil erosion in several studies using fertilizer as a surrogate. The intertemporal value would then equal the capitalized annual cost of replacing lost nutrients or soil over a defined period of time (Grohs, 1994).

The method can be used for all kinds of nutrient losses or budgets, not only erosion, and is simple to apply when such nutrient loss data are already available. If only soil loss data are available, nutrient contents

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[5] Organic fertilizers or local fertilizers, such as rock phosphate, are very seldom considered in replacement cost calculations, partly due to their restricted availability.

can be assessed through well-documented "enrichment factors" as eroded sediments contain higher nutrient concentrations as the soils from which they come (Stocking, 1986). Obviously, the **net nutrient balance** as determined with, for example NUTMON, offers a suitable base for the application of the RCA. Based on the net nutrient balance, the RCA addresses changes in on-site nutrient stocks but not the stocks themselves. In this case, off-site effects are not considered, although the RCA (as the PCA) can be a useful instrument in a separate assessment of, for example, reduced dam lifetime, capacity or yield.

Usually, "replacement" costs are calculated only for the lost nutrient *per* **se** (or the negative net nutrient balance) and do not consider the following factors that might increase or decrease the cost value:

- The question if the considered nutrients are, or will become, a limiting factor for crop growth.
- Available (fertilizer) nutrients are supposed to replace, in part, nonavailable nutrients.
- Fertilizer efficiency, i.e. the real costs of replacement would be higher if we take, for example, leaching of applied N and K into account during the replacement process.
- The additional labour costs for fertilizer application.
- Fertilizer retail price variations (especially of rock phosphate) following large-scale demand.
- Likely side-effects of large fertilizer applications on for instance, micro-nutrient availability and soil acidity (costs of liming).
- Not all nutrient loss is absolute due to deposition elsewhere on agricultural land.
- Increase in atmospheric carbon due to additional consumption of fossil carbon for fertilizer production.

Some of the above could be justified by the statement of Munasinghe (1992) that a major purpose of environmental valuation is not to provide fine-tuned numbers but to indicate orders of magnitude. However, the same author also concludes that greater application to practical problems in a developing country is required, rather than further theoretical development, of the environmental valuation concepts and techniques. With reference to the farmers' environment, the RCA is rather abstract. **In** a participatory approach to research it would be very difficult to explain to farmers to buy fertilizer that is almost as costly as the crops they produce. Other shortcomings of the RCA are described by Enters (1998a).

Box 7. Modelling nutrient balances and farm economics

Some recent studies try to link nutrient balance assessments with farm economics (Elias *et al.*, 1998; Shepherd and Soule, 1998; Defoer *et al.*, 1998; De Jager *et al.*, 1998b; Van den Bosch *et al.*, 1998), partly using a modelling approach. Van den Bosch *et al.* (1998), for example, included in NUTMON (see Box 3) a module for the calculation of economic parameters. The result "Farm-NUTMON" allows (i) estimation of the extent to which farmers generate income from soil nutrient mining, and (ii) assessment of the economic impact of external and internal changes at the farm and activity level. The authors use the **RCA** to assess nutrient costs (Van den Bosch *et al.*, 1998). An alternative model was developed by Shepherd and Soule (1998) with a **PCA** for cost assessment (soil-yield-functions) that supports long-term predictions. Grohs (1994) and Barbier (1998) combine the Erosion Productivity Impact Calculator (EPIC) with other models, such **as** CERES, to estimate yield impact and income losses due to erosion or other land degradation processes. These approaches also allow multiperiodic assessments.

Normally, the RCA is used without adjustments for fertilizer efficiency or nutrient availability. Both are from the biophysical point of view complex issues but require from the economic point of view some kind of abstraction with a focus on the monetary dimensions involved. The following sections present such approximations for the consideration of these two aspects. The economic literature on this subject is still very thin.

4.2.1 Adjustment for fertilizer efficiency

On most oxidic soils of SSA, about 30-70% of applied N, 50-60% of K, and on average 10-25% of P may be used by the crop in the season of application. The efficiency is not higher as applied N, for example, is lost largely through leaching, while phosphorus is transformed partly into nonavailable forms, of which again only a part will be become available over a reasonable time frame (e.g. 10 years). Therefore, it would be necessary to add more nutrients as compensation for these new losses, which would increase the replacement costs. As on average 50% of the N will be lost by leaching, the replacement costs could be multiplied by the factor 2 as a rough approximation of fertilizer efficiency. In the case of P, 12 months after P application, leaching losses will be negligible, but 40-60% of the originally applied P might be fixed irreversibly (Pagel *et al.*, 1982). A factor of 2 might be again a rough estimate; however, the exact correction factor will depend on the P-sorption characteristics of the soil, the kind of P fertilizer, and application timing (cf. Buresh *et al.*, 1997). It will be very low in the sandy soils of the Sahel with low P sorption, and very high in calcareous or some volcanic soils. Potassium not adsorbed by the crop, might be lost via surface runoff or remain fixed or available at the exchange complex. As leaching losses can be very low[6] (Pieri, 1992; Poss *et al.*, 1997), the correction factor for additional K application has only to account for K fixation if anti-erosion measures are in place (and K-rich residues are kept in the system). In southern Togo, this factor was determined as 1.2, i.e. extra K application (costs) of 20% (Poss *et al.*, 1997).

As most nutrient balance models, such as the original NUTMON, consider the soil as a black box (see Chapter 2), they do not differentiate between pools of different availability but focus on the total nutrient flows. Moreover, quantitative data for the fluxes between different nutrient fractions in the soil are largely lacking and difficult to assess. These fluxes depend, among others, on water availability and SOM characteristics. In most soils of the humid tropics, low SOM levels result in higher cation leaching. Therefore, the consideration of the costs of

[6] Verified on ferruginous soils of the West Africa savannah zone (Pieri, 1992) as well as on some ferralitic soils ("terre de barre") in southern Togo (Poss et *al.*, 1997). "Terre de barre" corresponds with Acrisols, Nitisols and/or Ferralsols according to different authors using the FAO/UNESCO classification.

SOM depletion (see below) could substitute in part fertilizer efficiency adjustments, for example for K.

In general, it would be easier from the economic point of view if the biophysical base was more sophisticated. But obtaining a better measure of the nutrient balance would demand more data input such as a good appreciation of agroclimatic conditions pertaining to the area as they affect the water balance and its impact on different nutrient pools in the soil. Only a few models try to consider these links (cf. Shepherd and Soule, **1998;** Noij *et al.*, **1993).** The target should be the right balance and incorporation of a workable biophysical assessment and a user-friendly economic valuation.

4.2.2 Adjustment for nutrient availability

Comparing PCA and RCA, Grohs **(1994)** and Bojö **(1996)** discussed different reasons for higher cost estimates with **RCA** than PCA. One reason mentioned (see above) was the consideration of replacement costs for nonavailable nutrients in eroded soil material that are not directly related to productivity. Therefore, it would be desirable to adjust for the plant-available nutrients as the comparison of partially plant-available nutrients with nutrients in fertilizers is problematic (Bishop and Allen, **1989).** While eroded soil includes nutrients with very low availability, the other nutrient in- and outputs in the nutrient balance concern more or less "available" fractions. Bishop and Allen **(1989)** assume that only **4%** of total nitrogen (N_{total}) would have been available in any given year, but **100%** of the "available" P (P-Bray) and exchangeable K measured in eroded material.

If total nutrient amounts have been analyzed in the eroded soil material (e.g. for the nutrient balance as done with NUTMON), then the available (or annually mineralizable) fractions of N_{total}, P_{total}, and K_{total} are very small. Although the values vary between different site conditions, the general amount is only a fraction (< 6%)[7] of the total nutrient content in the eroded soil (Pagel *et al.*, 1982), i.e. annually they are not very significant compared to other outputs of available nutrients. Thus the economic importance of nutrients lost through erosion becomes small

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[7] **Assuming +/- 5% did not affect the overall cost assessment in our case study (chapter 5).**

and the total depletion costs will decrease, if we value available nutrients higher than nonavailable nutrients. The figures would increase if the erosion data included fresh debris or green manure with (depending on amount and kind) large amounts of mineralizable nutrients (cf. Janssen, 1993).

The question that remains is: "What is the price of currently nonavailable nutrients?" A corresponding cost adjustment would be necessary if we wanted to give a value to the nutrient storage ability of soil or eroded SOM (cf. 6.3). Finally, we should ask how many nutrients should be considered for the cost assessment: All nutrients with a negative balance or those which limit growth, i.e. deficient? The answer to this last question will depend on the site and scale of interest. At the national scale we considered in our case study (Chapter 5) N and P as the most commonly deficient elements in SSA (Sanchez *et al.*, 1997) and K as a proxy for any other possibly deficient macro- or micro-nutrient.

4.2.3 Comparing PCA and RCA

Grohs (1994) explains the higher cost assessments with RCA than with PCA with different assumptions about sustainability and the nature of substitutability between man-made and natural capital. The author assumes several degrees of substitutability ranging from weak to strong. The weak sustainability criteria allow substitutions between man-made and natural capital as long as their sum is nondeclining. In contrast, the strong sustainability criteria require nondeclining stocks of man-made ***and*** natural capital.

This differentiation is used to show the varying limits for substituting soil productivity.

At the level of substitution between resources, soil productivity cannot be substituted viably against any other natural resource. This very ***strong*** sustainability criteria would therefore not allow any kind of soil mining.

Substitution between production inputs is conceivable in a way that soil productivity lost through erosion can be replaced partly by either enhancing soil productivity on the farm (manure, crop residues, N-fixing crops) or through external inputs (mineral fertilizer). The RCA is based on the strong sustainability constraint because it uses substitutes at the production-input level to value the costs of erosion. The RCA takes account of intergenerational equity, i.e. substitution of soil against other capital forms is only allowed if soil functions are restored but not to substitute for generated income.

Substitution between consumption streams means that services derived from the depletion of natural capital can be substituted by a similar good. The **loss** of soil productivity could be substituted by purchasing the services of the soil (food, fuel, fodder, etc.) in the form of a similar item produced at other locations. The "change of productivity" technique can be used to evaluate the costs of erosion under a *weak* sustainability constraint, i.e. substitutions will take place at the consumption level focusing on the efficient use of the soil for current generations.

The decision on which sustainability constraint to apply is mainly political in relation to how far environmental concerns are going to be integrated into policies. The level of sustainability can be implemented at various geographical scales. Nondeclining capital stocks can be required at the global, national, regional, or local level. At the level of substitution of resources (strong sustainability) solid productivity has to be maintained locally. Considering it as a production input, ideally it should be substituted locally, but it would be conceivable to substitute it on a regional or to some extent on a national level. The destruction of soil at a certain location is often compensated by restoring soils at other locations. The substitution between consumption streams (weak sustainability) is less attached to the local level. Purchasing and importing food from other countries is a common substitution for indigenous production (Grohs, 1994).

As mentioned above, the RCA and **PCA** address nutrient loss ***per se*** but do not consider information on the nutrient stocks to access the significance of the depletion. **A loss** of a certain quantity of nutrients might be tolerable at one site but exhaust soil fertility at the other. The following section presents an approach that considers nutrient stocks.

4.3 *Total factor productivity (TFP)*

Total factor productivity (TFP) calculates the ratio of the total value of all outputs produced by the system, to the total value of all inputs used during one cycle. This approach offers an alternative to the economic assessment of nutrient depletion via PCA or **RCA,** as the **TFP** emphasizes, besides economic efficiency, sustainability as well. Ehui and Spencer (1993) have extended the initially "economic" index to include the unpriced contribution of natural resource stocks and flows. The authors stress that economic approaches are biased unless changes in resource abundance levels (i.e. nutrient stocks) and flows are accounted for. Simpson *et al*. (1996) illustrate this in the case of Machakos, Kenya.

To measure both 'economic viability' and 'sustainability', Ehui and Spencer (1993) advocated separate calculations for the interspatial and intertemporal TFP, respectively. With regard to soil nutrients, the corresponding in- and output quantity indices are computed as the ratio of total expenditures to the weighted input price. In determining the cost share for the resource stock, the opportunity costs for each soil nutrient are approximated with its replacement cost, i.e. market price from chemical fertilizer. Resource flows are considered as the temporal or spatial difference between nutrient levels.

Intertemporal TFP (ITFP) is defined in terms of the productive capacity of the system over time. It is the rate of change of an index of outputs divided by an index of inputs, including both conventional inputs and outputs and the unpriced contribution of natural resource stock and flows. ITFP is an appropriate *measure of sustainability* as it addresses the question of change in the productivity of a system between *two* or more periods. A system is sustainable if the associated **ITFP** index does not decrease (Simpson *et al*., 1996).

For economic viability, a static concept is suggested, which refers to the efficiency with which resources are employed in the production process at a given time (Ehui and Spencer, 1993). A new production system can be said to be more economically efficient than an existing one if its total factor productivity is greater at a given point in time, i.e. the interspatial TFP *measures the economic viability* of one system relative to another at a given period (e.g. crop season).

To internalize external costs, such as environmental effects, a modification called total social factor productivity (TSFP) was proposed (Herdt and Lynam, 1992).

A disadvantage from the perspective of the natural sciences is that the TFP relies on prices. These must reflect the true value of resources and outputs to society if the TFP is to give realistic results. Another bottleneck is that the technique is mathematically demanding.

4.4 *Resource appreciation (1) - hedonic pricing*

Many aspects of the environment have no established direct market price. In these cases, economists estimate monetary values by means of the price paid for a surrogate good or service that is marketed (i.e. using an "implicit market") or by analyzing consumers' willingness to pay for certain natural resources or amenities assuming a hypothetical or artificial market (cf. section 6.4).

Hedonic pricing or property valuation is based on the assumption that the value of a resource is related to the stream of net benefits derived from it. This means the method presumes that the productive capacity of the land (or its physical degradation) is reflected in land prices, which in turn indicate the present value of net returns over time. Thus, the most direct approach to valuing nutrient depletion would be to compare the sale or rental prices of plots which differ only in the extent of their soil degradation. The degree of degradation, even of soil nutrient depletion, could be assessed, for example, through the type and intensity of the fallow vegetation or topsoil colour/structure. Usually, plot (rental) prices depend on many criteria. Fields may be abandoned due to weed encroachment and not due to nutrient depletion. Controlling all variables except for differences in soil productivity would be necessary. Pearce and Turner (1990) describe a mathematical approach to solve this problem that links to the willingness-to-pay analysis (section 6.4).

In practice, however, hedonic pricing is applicable only where land is a significantly constrained resource, land markets are well developed, and price data are available. A survey in peri-urban Kumasi, Ghana, where significantly reduced fallow periods and land shortage are well documented, did not indicate different prices for land of different quality or time under fallow (IBSRAM, unpubl.). A similar situation was found in Zimbabwe (Grohs, 1994). Such situations may be found in large parts of SSA where property rights are ill defined or when land markets are distorted by speculation, traditional tenure systems, or policy. Even when such complications do not arise, hedonic pricing does not address the full cost of soil degradation to society, as it captures only costs and benefits perceived by the parties to market transactions, i.e. the reduced productive capacity of the land. Off-site costs are ignored, as are losses arising from any divergence between private and social time preference (Bishop, 1992). If property prices are unavailable, farmers' willingness to pay (section 7.4) may be analyzed (in monetary terms or as scores) for land of less depleted soil fertility.

5. Umbrella approaches

The following chapters will introduce two integrated approaches that offer a framework for a more complex impact assessment of nutrient depletion. This can be based on the comparison of different land-use systems, e.g. with and without soil conservation, contain related cash flow analyses, and integrate results from **RCA, PCA** etc. while considering the criteria of farmers' decision making. While the **CBA** requires monetary values, the **MCA** integrates intangible criteria, that cannot be quantified in monetary terms, but, for example, via indices (TFP) or scores (contingent ranking; cf. section **6.4).** Within **MCA, CBA** can be used to address the economic efficiency criterion.

5.1 *Cost-benefit analysis (CBA)*

CBA is a useful tool in the appraisal and evaluation of soil and water conservation projects. It provides a coherent framework for integrating information on the biophysical and socioeconomic environments faced by farmers. The range of benefits and costs that can be included in a **CBA** is potentially large. While simple techniques, such as calculating the value of lost nutrients **(RCA, PCA)** can only roughly indicate the severity of the problem, **CBA** gives guidance towards more complex assessments by considering, besides market prices, opportunity costs or shadow prices addressing, e.g., the farmers' points of view as well. CBA is applied usually in a comparative analysis of different land-use and soil conservation techniques that compare costs and benefits related to different nutrient balances (with – without analysis). CBA starts with the identification, specification, and evaluation of expected effects of an intervention. Such effects occur at the input side (labour use, capital) and on the output side (produced commodities). According to Enters (1998b) the main steps of the CBA are:

- Identification of all components relevant for the analysis.
- Quantification of physical variables and their impact, especially yield changes.
- Valuation of the costs and benefits of the quantified impacts.

The method, its limitations, and examples of its application have been discussed comprehensively by Pearce (1983), Barbier *et al.* (1990), Bojö (1992), Hanley and Spash (1993), Lutz *et al.* (1994), De Graaff (1996), and Enters (1998ab).

Benefits and costs can be valued in different ways depending on whose point of view is taken. In the **social CBA,** the cost and benefits of an investment are calculated for the society as a whole, and all the costs and benefits of a given activity must be considered, also the off-site impact. In private CBA, the cost and benefits of an investment are calculated for a project or farm. A major objective of the *private* analysis of farms is to judge how much impact a proposed investment will have on farm income. The private perspective is therefore that of individual rationality, and is an important way of predicting the likelihood of adoption of a proposed intervention or whether a household could afford to divert labour to soil Conservation from another activities (Stocking and Abel, 1989). In contrast to the social point of view, farmers are likely to consider only the costs and benefits that actually accrue to them from the decisions they make about how to use their resources. They value these costs and benefits at prices they actually face (Lutz *et al.*, 1994). In a careful analysis of a situation and expected changes over time, it **is** possible to value as costs and benefits all quantified impacts. **A** simple example is given in Table 3.

CBA can also be applied *in* cases where intangible costs and/or benefits are of concern. **If,** for example, two alternative **soil** conservation measures are compared with similar intangibles, the quantifiable

Table 3. Example of selected individual and social costs and benefits through nutrient replenishment in peri-urban Kumasi, Ghana.

Nutrient improvement practice	cost	Benefits
Application of poultry manure (PM) and mineral fertilizer	***Individual:*** Fertilizer costs; transportation costs; application cost (incl. opportunity cost of family labour; monetary costs of hired labour), opportunity cost of possible reduced germination; increased risk of crop los due to lack of knowledge of PM application rates and time (nonmonetary). ***Social:*** Water pollution through excessive PM applicatio rates. Vegetable contamination through fresh PM with *E. coli.*	***Individual:*** Increased yields through increased soil fertility (monetary). ***Individual and social (nonmonetaty):*** Reduced amounts of dumped PM litter; increased sustainability of the system through less risks of yield fluctuations; improved soil resource base: increased biodiversity of soil fauna and flora; reduced erosion through higher ground cover.

variables may be sufficient to select the better alternative. In other cases, the social profit or loss of a certain project may be evident strictly on the basis of quantified data, and signs of intangible variables will simply reinforce that result. In remaining cases, CBA has at least specified the basis for judgment – an important gain (Bojö, 1992).

When benefits cannot be quantified properly or are not demanded, CBA can be reduced to **cost-effectiveness analysis** (CEA) (cf. Gilpin, 1995; De Graaff, 1996). Certain (especially intangible) goals may be so evident to decision-makers that it is not necessary to specify any benefit estimation, for example ecological, social, or educational benefits. CEA is essentially a cost minimization exercise in achieving a particular objective, i.e. for a given (or alleged) benefit, CEA is about the least-cost approach to the objective. It might be applied to (indispensable) soil conservation measures or to compare options that contribute the least to, for example, global warming. In some cases it is best to combine both CBA and CEA, when some benefits are measurable and others are not.

5.2 Multi-criteria analysis (MCA)

With the MCA we go beyond valuations in currency/monetary units. MCA allows us to value as well nonmarket goods or the intangible side-effects of nutrient and carbon depletion, such as microbiological activity. Various evaluation criteria may be used with different units (monetary, scores, or qualitative ranks).

The normal framework (CBA) for the analysis of decision making pre-supposes a focus on one well-defined objective, that is economic efficiency or profit. However, decision-makers in the agricultural sector have a strong motivation to seek optimization or satisfaction of several objectives or goals, instead of maximizing only one. Such an (additional) objective can be "sustainability" (cf. ITFP) or the protection of an endangered species that might be unrelated to any actual or potential use of a good. In MCA, alternatives can be judged on their contribution towards different criteria, and the respective variables or criteria do not have to be quantitative, and each of them can be expressed in their own respective units (e.g. via scores). Weights have to be given to the respective units to find the optimal alternative. These weights can be established through expert knowledge, by interviewing people concerned ("participatory monitoring and evaluation") or directly by the decision-makers themselves. Criteria may be a decline in soil biological activity, increased food insecurity, water pollution, etc.

A wide array of MCA methods has been developed, some deal with either qualitative, quantitative or both types of data, some are more sophisticated, others less so. The different methods can also be classified, for example, according to the way of aggregation of criteria. Application examples of two MCA methods are described by De Graaff **(1993).** The general sequence of analytical steps in MCA includes (De Graaff, **1996):**

- Determination of objectives
- Defining alternatives
- Formulation of evaluation criteria
- Determination of effects of alternatives on criteria
- Construction of evaluation matrix
- Standardization of effects
- Formulation of weight vectors
- Formulation of aggregation rules
- Ranking of alternatives
- Checking for satisfactory ranking.

For the assessment of nutrient depletion, CBA has the drawbacks that all effects have to be valued in monetary terms. In MCA it is not necessary to undertake a detailed quantification and valuation of various costs and benefits, thus it can avoid detailed research and calculations. MCA has on the other hand the disadvantage that it does not allow for an easy comparison of streams of costs and benefits over time, and that it basically relies on subjective weights attached to several criteria by the groups concerned and represented. An intermediate solution is the use of the results of the CBA as one criteria (economic efficiency) to be used in the MCA (De Graaff, 1996).

6. Relating nutrient depletion to economic growth – the case of SSA

In this chapter the on-site costs of nutrient depletion from the national perspective in SSA have been assessed on the basis of the results presented by Stoorvogel and Smaling (1990), adjusted for nutrient availability, and an IBSRAM fertilizer price survey. A related paper on the relations between nutrient depletion in SSA and land pressure indicators was prepared by Drechsel and Penning de Vries (in press).

The RCA and the PCA have been discussed by Bojö (1996) in an often cited comparative study of the economic losses (mostly) due to soil erosion in eight countries of SSA (tables 4 and 5). Some of the 12 studies reviewed by Bojö (1996) also consider nutrient losses due to the removal of crop residues and dung or the nutrient balance. Off-site effects have been addressed in only three studies. Bojö (1996) discussed the different assessments of nutrient losses by different authors working in the same country (Table 4). In a following step, the author presented the monetary value of the productivity loss (or nutrient replacement) compared with the agricultural share in the agricultural gross domestic product (AGDP) and other economic indicators. The gross annual immediate loss (the lost value of that year's production) ranged from under 1% of the AGDP in Ethiopia, Madagascar, Mali, and South Africa, to 2-5% of the AGDP in Ethiopia and Ghana, and exceeded 8% in Zimbabwe (Table 5).

Box 8: Relating nutrient depletion to farm income

At the farm or community level, it is interesting to analyze the nutrient mining intensities of different farm types and to compare the cost of nutrient depletion with farm income.

Case studies, from Kenya and Malawi, verified significant interrelations between nutrient depletion and market economics. De Jager *et al.* (1998b) showed that a high market orientation correlates with a more negative N and K balance. The market-oriented farms located in highly populated areas are characterized by intensive crop and livestock activities. They import nutrients through fertilizers and/or animal feed, but this proved to be insufficient to compensate the outflow through marketed products, leaching, and erosion. There may be no direct relation between net farm income and nutrient mining (De Jager *et al.*, 1998b), but the contribution of soil decapitalization to the farm income can be quite substantial as studies in southern Mali and Kenya indicate. In a case study from Kenya, the replacement costs of mined nutrients were equivalent *to* more than 30% of the average net farm income (De Jager *et al.*, 1998b; Smaling, 1997), in Mali on average, 44% (Van der Pol, 1992). This suggests that only about 60-70% of farmers' income is sustainable. Otherwise, he or she is taking a loan on future production capacity.

Table 4. Results and valuation methods used in erosion studies in SSA (cropland national averages)

Country/study	Physical loss ($t\ ha^{-1}$, gross/net)	Productivity loss (% p.a)	Productivity loss (% cm^{-1})	Method
Ethiopia:				
FAO, 1986	130/100	1-3	1.3-3.9	PCA
Sutcliffe, 1993	45	0.6-0.8	1.8-2.3	PCA*
Bojo and Cassells, 1994	42/20	0.4	2.6	PCA*
Ghana:				
Convery and Tutu, 1990	n.a	n.a	n.a	RCA
Lesotho:				
Bojo, 1991	20	1	5.0	PCA
Madagascar:				
World Bank, 1988	n.a	10	n.a	PCA
Malawi:				
World Bank, 1992	20	4-11	26-72	PCA
Mali:				
Bishop and Allen, 1989	6.5	2-10	40-100	RCA/PCA
South Africa:				
McKenzie, 1994	5	0.04-0.1	1-3	PCA
Zimbabwe:				
Stocking, 1986	50	n.a	n.a	RCA
Norse and Saigal, 1992	n.a	n.a	n.a	RCA
Grohs, 1994	43	0.3-1	1-3	PCA

Source (also for cited references): Bojö, 1996; see also Scherr, 1999.
* **Considers nutrient loss through dung and crop residue removal**

Table 5. Cross–country comparisons: Economic loss measures through soil erosion and nutrient depletion.

Country/study	Annual production loss/ replacement costs		Valuation method
	US$M	%AGDP	
Ethiopia:			
FAO, 1986	14.8	<1	PCA[2]
Sutcliffe, 1993	155	5	PCA[4]
Bojo and Cassells, 1994	130	4	PCA[4]
This study	328 – 378[1]	10 - 11	RCA[3]
Ghana:			
Convery and Tutu, 1990	166.4	5	RCA
This study	115 - 136	4 - 5	RCA[3]
Lesotho:			
Bojo, 1991	0.3	<1	PCA
This study	5 - 6.5	5 - 7	RCA[3]
Madagascar:			
World Bank, 1988	4.9-7.6	<1	PCA
This study	90 - 127	6 - 9	RCA[3]
Mali:			
Bishop and Allen, 1989	2.9-11.6	<1	PCA
This study	72 - 85	5.5 - 6.5	RCA[3]
Malawi:			
World Bank, 1992	6.6-19.0	3	RCA/PCA
This study	84 - 99	9.5 - 11	RCA[3]
South Africa:			
McKenzie, 1994	18	<1	PCA[2]
Zimbabwe:			
Stocking, 1986	117	9	RCA
This study	28 - 40	2.5 - 4	RCA[3]
Norse and Saigal, 1992	99.5	8	RCA[3]
Grohs, 1994	0.6	<<1	PCA[2]

Source for cited references in Bojo (1996)
1. The range considers price variations of available fertilizer types and transport.
2. Considers in one or another way off-site effects.
3. Considers the nutrient balance, i.e. different in- and outputs.
4. Includes nutrient loss through dung and crop residue removal.
AGDP: Agricultural GDP 1994 (1996: this study).

A replacement cost assessment of annual NPK depletion (Σ outputs $- \Sigma$ inputs) in the same countries as compared by Bojö (1996) is included in Table 5. Its bases are the national nutrient balance predictions for the year 2000 by Stoorvogel and Smaling (1990) and a recent fertilizer retail price survey by IBSRAM (unpubl.). The data have not been discounted. The costs are conservative as they only address nutrient depletion *per* se, i.e. they do not consider additional fertilizer requirements due to limited fertilizer efficiency. Actual use of organic manures and off-site effects (only nutrient inputs through sedimentation) are considered in the net nutrient balance (NUTMON). However, for the replacement, it is assumed that the amounts of organic manures cannot be increased significantly. The availability of eroded nutrients has been addressed as described above. With regard to the overall costs of nutrient depletion, sensitivity analysis did not show any significant effect assuming 10% of eroded NPK is available instead of 5%.

Corresponding data for other countries in SSA derived from our assessment and the calculation used are described in Appendix 1. The data are given as a range to indicate possible price variations due to the available fertilizer type, its requested quantity, and necessary transport. The differences in depletion costs between the countries result from differences in nutrient in- and outputs and the size of the different affected production zones.

The figures given by Bojo correspond approximately with our estimations if we compare only replacement cost approaches (Table 5). However, if we compare our RCA results with PCA data, we will get large differences as already noted by Bojo (1996) and Grohs (1994) comparing RCA and PCA even in the same country (cf. 4.2.3).

Appendix 1 shows that in certain countries, such as Rwanda, Tanzania, Mozambique, and Niger, nutrient depletion accounts for 12% or more of the agricultural share in GDP, indicating nutrient mining as a significant basis of economic growth (Table 6).

Countries	% of AGDP
Benin, Botswana, Cameroon, C.A.R., Dem. Rep. Congo, Rep. Congo, Gabon, Ghana, Guinea, Kenya, Mauritania, Mauritius, Senegal, Sierra Leone, Swaziland, Zambia, Zimbabwe	≤ 5
Angola, Burkina Faso, Burundi, Chad, Côte d'Ivoire, Ethiopia, Lesotho, Madagascar, Malawi, Mali, Nigeria, Senegal, Togo, Uganda	6 - 11
Mozambique, Niger, Rwanda, Tanzania	>11
SSA (average)	7

* Only for countries where AGDP data were available (www.worldbank.org; 1999).

Table 6 also shows that for the whole of **SSA** nutrient mining accounts for about 7% of the subcontinental **AGDP.** Dividing the total costs of nutrient depletion in **SSA (US$3922 M)** by the population engaged in agriculture shows that every farm member contributes about US$32 to the annual nutrient deficit on the subcontinent. Related to annual and permanent cropland in **SSA,** the average **costs** are about US$20 ha^{-1} y^{-1}.

7. Economic valuation of soil carbon depletion

Literature on the importance and functions of soil carbon and SOM **is** extensive while environmental or economic literature has made some very limited attempts to approach its economic assessment. The following sections will outline possible approaches to close this gap and hopefully catalyze more discussion on the subject.

In general, costing soil carbon depletion (SCD) is more difficult than costing nutrient depletion for distinct reasons:

- *Good* estimates of the net carbon (or SOM) balance are very difficult to obtain (see following section).
- The application of (fresh) biomass cannot replace SOM as SOM consists of pools of different age, resistance, function, and activity, with correspondingly different benefits. The absolute **SOM** content (and parts of the various **SOM** functions) can be maintained only through regular and usually huge farmyard manure or compost application.

Thus, with little information about the net loss *of* carbon (i.e. the quantity to be replaced) and the market price of any direct - and available in larger quantities - SOM replacement, the **RCA** is difficult to apply for SOM ***perse,*** but might be useful for certain SOM functions and benefits with market price (cf. 6.3). **A** related, but more indirect (i.e. more vague) method is the **substitute goods approach** (cf. 6.3). The **PCA** appears particularly appropriate for an integrated assessment *of* SOM loss with eroded soil material (cf. 6.2). **As** all these approaches might become data demanding, a third, more consumer-oriented approach is presented, which addresses farmers' willingness to pay in the framework of **contingent valuation** (cf. 6.4).

7.1 *Soil carbon depletion*

For a long time soil carbon depletion (SCD) has been recognized to be a major process of soil degradation in tropical environments where shifting cultivation is practiced (Nye and Greenland, 1960, 1964; Van Noordwijk *et al.*, 1997). **As** with soil nutrient depletion, carbon depletion is linked mostly to a disturbed balance of inputs and outputs of carbon through cultivation.

It appears that the clearing and use of tropical soils affects their carbon content to a soil depth of about 40 cm. Soils of tropical open and closed forests contain approximately 5-7 kg C m^{-2}; to this depth (Detwiler, 1985). Following the clearing of a forest, all of the belowground biomass (on average **25%** of total biomass) and parts of the damaged/partially burnt aboveground biomass (together on average 30-50% of total biomass) decay exponentially at rates allowing 95% of the material to disappear over 6-10 years assuming continuous cropping. The rest of the aboveground biomass is either burnt or oxidized over periods of up to 1000 years (Houghton *et al.*, 1991). The authors summarize a range of studies indicating about 20-30% of soil carbon in the top 100 cm may be lost following tropical forest clearing for cultivation. With respect to the topsoil, carbon contents may be reduced by 40% (Detwiler, 1985).

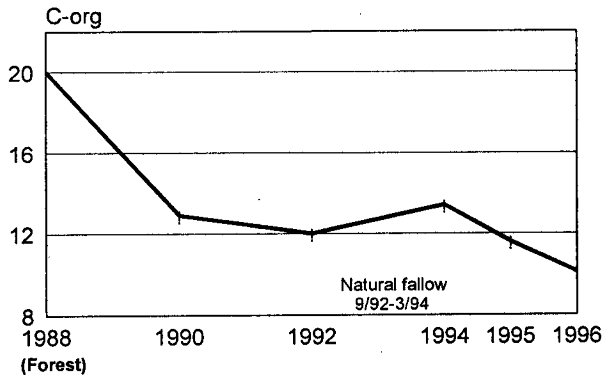

Figure 4. Decline of SOM (mg C-org g^{-1}) during cultivation (IBSRAM, unpublished data from Bécédi, Côte d'Ivoire).

Most of the loss occurs during the first five years of cultivation (Figure 4), the rest is lost over the next 20 years. This corresponds with an average decomposition of 15-20 t C 5 y^{-1} (Houghton *et al.*, 1991). This reduction in soil carbon content may have drastic effects on physical and chemical soil properties, such as N mineralization, as it involves the most active fractions of soil C (Van Noordwijk *et al.*, 1997).

Less SOM is oxidized during the shifting cultivation cycle than during continuous cultivation. Different studies give a range of 15-30% of the C loss in the top 100 cm (Detwiler, 1985; Houghton *et al.*, 1991; Nye and Greenland, 1964). However, the recovery of SOM may require 35 years of fallow after abandonment (Detwiler, 1985).

The primary effect of fire is to combust carbon in the vegetation of the forest floor. SOM, especially labile C, associated with macro-aggregates in the top 2 cm of mineral soil may be affected (Garcia-Oliva *et al.*, 1998; however, the combustion of SOM is limited largely to this layer due to the rapid drop of temperature with depth.

On the other hand, microbiological activity and related SOM decomposition may increase through both soil heating and chemical changes[8]. These losses are balanced partly (quantitatively) through a rise in the concentrations of elemental carbon (charcoal) in the upper centimetres of the soil. Different studies show that 2-14% of the total C stock in the vegetation before burning may be converted to elemental C (Houghton *et al.*, 1991).

In general, three factors contribute to the net decline of SOM during cultivation (Tinker *et al.*, 1996):

- Higher topsoil temperatures leading to higher decomposition rates.
- Lower litter inputs.
- Increased SOM oxidation caused by tillage, i.e. increased aeration and aggregate breakdown.

A fourth factor that can be crucial on sloping lands, and which is facilitated by aggregate breakdown, is erosion. Erosion relocates the SOM-rich topsoil layers. Assuming sloping lands with a soil loss of 35-75 t ha^{-1} (i.e. the upper 2-5 mm with comparatively high C concentrations of 5% for example) we can get 'gross' carbon losses of about 2-4 t ha^{-1} y^{-1}. Leaching of organic anions and bicarbonates, on the other hand, is a minor factor of soil carbon depletion (Smaling and Oenema, 1997).

In comparison with the assessment of the NPK balance, direct measurements or assessments of C in- and outputs are more difficult, especially at field and farm scales. The exchange rates of CO_2 between atmosphere on the one hand and biomass and soil on the other hand are too high to allow good estimates about the net carbon balance. Most models therefore address larger scales (cf. Detwiler, 1985) although attempts to evolve quantitative approaches to the SOM balance exist (Pieri, 1992). In fact, for the practical assessment of sustainability

[8] Also lower decomposition rates are possible due to a reduced soil moisture content (Ewel, 1976).

the “net carbon balance” might be a less suitable indicator than the assessment of the total **loss** of soil carbon, or better, **SOM.** In contrast to NPK or other nutrients, carbon and the carbon balance ***per se*** are less crucial for the economics of agricultural sustainability than the **loss** and build up of SOM. SOM is the most meaningful transformation product of soil carbon and has a direct use value and generates different service flows at different levels. It benefits individual farmers since it contributes to soil fertility and agricultural yields, but it also benefits society as it contributes to agricultural sustainability and food self-sufficiency.

Box 9: Modelling carbon dynamics

Besides the approach of Pieri (1992) for a site-specific organic matter balance, most carbon models focus on larger (regional) scales and the carbon dynamic. The **Century** model is a well-known ecosystem model originally designed to study SOM dynamics over periods up to several thousand years. It can simulate soil C, N, P, and S dynamics under consideration of two litter fractions and three organic matter fractions, and was used successfully to study, for example, maize production and management-related **SOM** changes (Paustian *et al.*, 1997). **DYNAMITE** is a model that stands for Dynamics of Nutrient and Moisture in Tropical Ecosystems. It was developed from NUTCYC, a model developed for the analysis of C, **N**, P, and K cycling in tropical forests. Although the main outputs are data on the biomass development in a tropical forest, it considers nutrient flows between organic and (different) inorganic pools, soil solution, nutrient uptake, leaching, erosion, etc. that allow impact assessment of changes in management and environment (Noij ***et al.***, 1993). Other carbon models are described by, for example, Paustian *et al.* (1997) and Chertov and Komarov (1997).

7.2 Costing SOM loss through erosion (integrated approach)

Due to the close relation between the (mostly) organically-bound elements C, N, P, and S, it is recommended to cost erosion-related SCD as an integrated part of soil erosion and related nutrient losses. This can best be done mutually through soil **loss** – plant productivity equations, i.e. via the productivity change approach (PCA, section 4.1). The advantage of the PCA is that there is no need to give a separate value to certain active or passive, labile or stable SOM fractions, their different functions and related benefits, such as water-holding capacity or cation exchange capacity. All lost benefits will be translated into the **loss** of crop yield and farm income; no single nutrient/benefit will be overemphasized. The PCA has its limitations when more depletion processes have to be addressed simultaneously (cf. 4.1), but can be used as well to value possible benefits of off-site SOM sedimentation, thus allowing an assessment of the costs of 'net' carbon erosion[9].

7.3 Costing different SOM functions

SOM functions (services) that are appreciated by the farmer (e.g. nutrient supply) may be valued by using the direct market price of ***similar goods,*** e.g. fertilizer (RCA, section 4.2) or by approximating the value of the next best alternative/substitute good with or without a market price (e.g. compost or manure). This can be called the **substitute goods** approach. It is, like hedonic pricing, another surrogate market approach using implicit markets. The extent to which the value of the marketed good reflects the value of the nonmarketed good of interest depends, to a large extent, on the degree of similarity or substitution between them. That is, if the two goods are perfect substitutes then their economic values should be very close. As the level of substitution decreases so does the extent to which the value of the marketed item can be taken

[9] The effect of SCD on the global C budget depends on what happens with the removed topsoil and its carbon on the sites of deposition, not removal (Van Noordwijk et *al.*, 1997).

as an indication of the nonmarketed item (Nunan and Bishop, 1999). The value can be determined as the shadow price, opportunity costs, or artificial market prices derived from farmers' willingness to pay (section 6.4) for the SOM functions in question.

Box 10: Market and shadow prices of organic carbon

Shadow and market prices are difficult to compare as they depend on the point of view or objectives of their development as the following examples show:

- In northern Europe, gardeners use nutrient-poor and acid peat (Histosols) for soil structure amelioration and water retention. In Germany and Switzerland, they pay 100 Fr (or DM) per m^3 of peat. That is about US$240-330 per metric ton of carbon (only) to improve soil structure.
- At an international expert meeting on global warming **(FAS,** 1996), participants recommended a shadow price in the order of US$10 or 20 (US$5 to 40) per metric ton of carbon emitted to reflect a broad range of potential damages from the increase of greenhouse gas concentrations in the atmosphere. This magnitude is consistent with the marginal damage estimates reported in the IPCC review of the literature on global impacts of climate change (Pearce *et al.*, 1996).
- With regard to C sequestration through agroforestry in African smallholdings, Woomer *et al.* (1998) estimated input costs (rock phosphate, tree seedlings, labour) of US$87 per ton of carbon. Significantly lower costs (< US$10) are possible via tropical tree plantations (Dixon *et al.*, 1993).

The approach assumes that different functions of SOM can be substituted through different (soil) inputs and the sum of the prices/ costs of these inputs would allow the estimation of a shadow price (Izac, 1997). In a first step, it is important to determine the point of view, i.e. which tangible and intangible SOM functions and benefits should be considered.

According to a survey carried out by IBSRAM in different zones of Ghana, farmers see the major advantages of SOM to be: nutrient supply, nutrient reservoir, water storage, and its positive impact on soil structure and related labour input (Drechsel and Yirenkyi, 1999). These characteristics correspond largely with the scientific point of view (Janssen, 1993) and give us a possible frame for the economic valuation of SOM. However, we have to keep in mind that not all functions of SOM are of relevance at any time and at any place. The water holding benefit, for example, is less important in soils with loamy texture and under sufficient rain. On the other hand, there are more (mostly indirect) SOM benefits; for example, interaction with soil fauna/flora. However, this is in part covered by the other functions (water, nutrients, structure) that support or benefit from it.

Izac (1997) used a comparable approach looking for the degree of agricultural intensification, and how the various benefits of SOM could be substituted through man-made inputs as intensification increases. Figure 5 shows the different levels of intensification on the x-axis, from slash-and-burn to hydroponics. The various functions of SOM are substituted increasingly by different inputs (inorganic fertilizers, irrigation water, etc.) with higher intensification levels. It follows that the shadow price of SOM is equal to the sum of the prices/costs of these various substitutes (Izac, 1997).

Quantification of physical effects: In the following step we have to analyze the **degree of similarity** between the benefits and their substitutes or replacements. An example might be the question of how many kilograms of charcoal replace how many kilograms of fuelwood. The ratio is certainly not one to one but even if we know that x kg charcoal replace y kg fuelwood we do not know the farmers' assessment, which also depends on intangible parameters like different burning characteristics (intensity, duration, smell, etc.). Certain African dishes, especially smoked fish or grilled meat require specific wood or charcoal as fuel.

The case of SOM is similar. However, if we are to progress from purely descriptive economy to a more quantitative cost assessment, it is necessary to look for empirical guidelines. Some of the following examples are based on generalized empirical relationships, which can

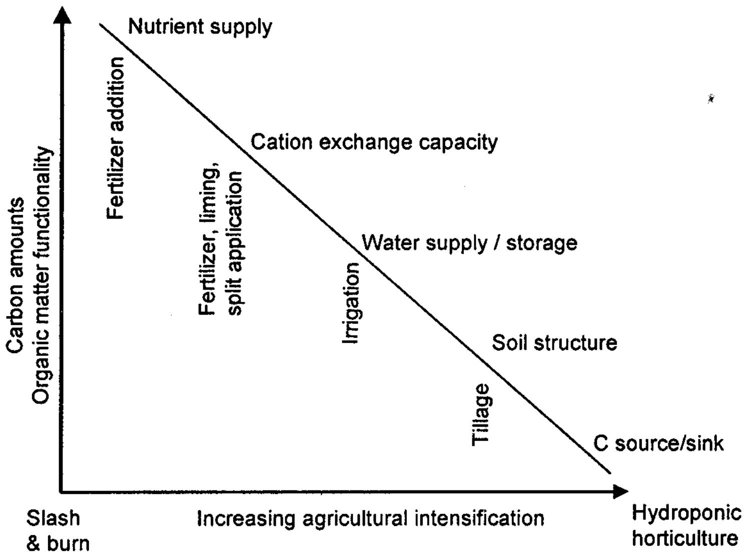

Figure 5. Principal functions of soil carbon with increasing agricultural intensification and the technical replacements (substitutes) during agricultural intensification (Izac, 1997; modified). Original in *Geoderma* 79: 274, with permission from Elsevier Science.

give an idea about magnitudes. Fine-tuning or modifications are possible if corresponding soil data are available. The following examples are in part mutually exclusive, i.e. in combination would result in double counting.

Nutrient supply: If we study nutrient losses in general, for example with NUTMON, then the losses of NPK etc. linked to SOM are considered already because the total amounts of nutrient inputs and outputs are analyzed. Depending on the time horizon, a cost adjustment for nutrient availability will be necessary. This will show that the annually mineralizable N and P fractions in SOM are small if we exclude the input of fresh (green) biomass.

Valuation: Via RCA (fertilizer price, see Appendix 1) with cost adjustment for nutrient availability (see 4.2.2).

Nutrient storage function: If value should be given to SOM as a nutrient store then a longer time frame is addressed and the (short-term) adjustment for nutrient availability (see above) has to be modified correspondingly. If we give full value to stored nutrients (assuming a complete mineralization in the long term) the "availability adjustment" might be neglected.

SOM contributes especially to the cation (K, Ca, Mg) exchange capacity (CEC) in tropical soils with low-sorption clay minerals. Reduced CEC results in increased leaching and can only be substituted by additional synchronized cation application, i.e. "at the right time of plant demand".

Valuation: One possibility is via RCA with modified cost adjustment for nutrient (cation) availability or a correction factor for additional cation application. The loss of 1% of SOM corresponds on average[10] with a loss of exchange capacity of about 20-30 $mmol_c$ kg^{-1} soil. In other terms, we can say as a rough estimate, and as a simplified assumption that if the exchange complex is only occupied by K, that for 1000 kg of lost SOM an extra supply of about 100 kg K would be necessary assuming 100% fertilizer efficiency. This gives us a magnitude of additional fertilizer cdsts, which could be used to value the storage benefit. Additional split application will increase labour costs.

Water holding: The available water holding capacity, especially of light textured (sandy) soils, benefits from SOM. Although the function is not linear we estimate that one additional percent of SOM adds about 2 vol%[11] available water capacity (AWC). This can be a significant amount in coarse sandy textures, but becomes relatively small in loamy or silty soils with high texture-related AWC.

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[10] The value depends on soil acidity and SOM characteristics (Pagel *et al.*, 1982).

[11] The value depends on SOM characteristics and might vary between 1 and 4 (AG Bodenkunde, 1982; Janssen, 1993).

Valuation: For 1000 kg of lost SOM, approximately 1.3 m^3 less water is stored in the soil. The irrigation quantity could be used (RCA, substitute goods approach) to value the water storage benefit assuming 100% irrigation efficiency and *de facto* insufficient precipitation. As water supply might be free, the labour input (or its opportunity costs) may be used

However, in the case of erosion, it might be more useful to estimate the costs of the total AWC loss (texture-AWC plus SOM-AWC) with or without the loss of nutrients via the PCA.

Friability of soil structure: Possibilities to counteract reduced friability may include for some soils more tillage and/or additional biomass application (to loosen the soil and/or stimulate soil fauna) if we exclude artificial substrates. On the other hand, both approaches (tillage, biomass) may enhance soil biological activity and more consumption of soil carbon; and tillage, if badly done, may also increase the risk of erosion.

In areas with still abundant land and minimum tillage (only sowing), as in large parts of humid West Africa, the costs of additional biomass application might function as a “structure surrogate”, while increased tillage efforts might be a substitute in the East African highlands.

Valuation: Via the costs of additional labour input (or opportunity costs of labour) for tillage or biomass transfer.

Pieri (1992, 1995) points out that there are critical levels of SOM below which production declines seriously as the soil becomes liable to physical degradation (loss of structure and erosion). With regard to the long time span necessary for SOM buildup, the economist has to decide about the most adequate mechanism (e.g. real social discount rate) to consider that some SOM-related functions cannot be restored within a reasonable period of time (e.g. one human generation). The threshold concept of Pieri might set up *safe minimum standards* to prevent irreversible damages as a decision support instrument in situations where alternatives are available (cf. Grohs, 1994).

7.4 Resource appreciation (2) - farmers' willingness to pay or accept

Willingness to pay (WTP) is a term economists use to express the level of demand felt by consumers for a particular good or service, which normally is not traded in markets. WTP is analogous to price in the sense that it expresses a monetary value which may be compared to other priced or unpriced goods and services (Nunan and Bishop, 1999). The method might be applied to value the various functions and benefits of SOM from the farmers' points of view assuming a hypothetical situation or artificial market **(contingent valuation).** The method also allows an indirect assessment of soil fertility depletion, via the estimation and valuation of farmers' possibilities to spend more labour on soil conservation.

The standard approaches of the contingent valuation method (CVM) are questionnaire-based surveys of the target population (Mitchell and Carson, 1989). The interviewer suggests the first bid and the respondent agrees or denies that he/she would be willing to pay it. An iterative procedure follows: The starting price would be increased to see if the respondent would still be willing to pay it, and so on until the respondent declares that he/she is not willing to pay the extra increment on the bid. However, a poorly designed or badly implemented survey can easily influence and bias responses, leading to survey results that bear little resemblance to the relevant population's true WTP. Resolving these difficulties involves careful design and pre-testing of the questionnaire, competent survey administration and the execution of econometric tests that can help identify sources of bias. CVM works best when the respondents are already familiar with the resource to be valued, when the hypothetical market is realistic, and when the respondents have already some experience in trading the resource in question (Pearce and Turner, 1990; Nunan and Bishop, 1999; Hanley and Spash, 1993).

A simplified[12] version of the method is **contingent ranking,** a matrix ranking exercise suitable for participatory on-farm appraisals, that uses scores to estimate WTP for a number of goods and services (i.e.

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[12] The technique can be, however, statistically more demanding than CVM (Hanley and Spash, 1993).

nonmonetary values). According to farmers' awareness and perceptions of individual SOM benefits, a benefit package can be scored for each benefit separately. As matrix ranking is also used for *environmental impact assessment* (EIA) similar constructed economic evaluation techniques might also be integrated into an established EIA tool kit (Gilpin, 1995).

A WTP-related concept is **willingness to accept** (WTA) compensation, which refers to the amount of money that consumers would demand in compensation to give up a particular good or service. Here the questionnaire process works in reverse: bids are systematically lowered until the respondent's minimum WTA is reached. The question might be: How much compensation would a farmer demand for taking fields with different SOM levels out of production or to tolerate deterioration?

The CVM can address off-site costs if the exercise covers correspondingly affected off-site areas and farmers' WTP or WTA for a potential benefit or burden. In a similar way, people may be asked to value "climate change".

A comprehensive discussion of these methods with regard to natural resources in general was presented, for example, by Mitchell and Carson (1989), Pearce and Turner (1990), and Hanley and Spash (1993).

8. Conclusions

In IBSRAM's Issues in Sustainable Land Management no. 1, Clem Tisdell wrote that economics do not give cut-and-dried answers, but merely provide a set of tools to be used in analysis. Furthermore, he stated, no single operational concept of sustainability is available from economics. In fact, resource benefits are perceived and valued differently by different groups in society also depending on the scales at which they occur. What is deemed relevant in a given situation will vary according to the different priorities and interests of different stakeholder groups, reflecting the risks and opportunities they face. Which method is the most appropriate for nutrient depletion with regard to its complex nature and time frame? The choice of the valuation method depends on the decisions that have to be taken, keeping in mind that the results will largely depend on the economic valuation technique chosen. Each has advantages and limitations. Considering that soil is a natural resource with its associated costs and benefits, policies, markets, and institutions, its economic valuation calls for an interdisciplinary approach. The target should be a compromise between appropriate biophysical assessment and user-friendly economic valuation according to the objectives of the individual study

With regard to soil nutrient depletion, the nutrient balance approach offers an interesting biophysical base for its economic assessment via the RCA as the net nutrient balance can be transferred directly into fertilizer costs. Adjustments for fertilizer efficiency, nutrient availability, and SOM depletion, have been suggested.

In comparison with the different depletion processes, soil erosion addresses more soil benefits than nutrient supply alone, and erosion-related productivity loss (loss of soil depth, nutrients, SOM and related benefits) is best valued jointly with the PCA. The RCA, on the other hand, only values some soil functions, leading to an undervaluation of the whole resource but overvaluation of the nutrients that are not in short supply.

Comparing PCA and RCA, it is possible to say that the change of productivity technique reflects the financial costs to the farmers who use the soil to gain an income, while the RCA reflects more the costs the current generation imposes on the future generations by depleting the soil. But RCA and PCA cannot distinguish between reversible and irreversible damages, and do not include adequately intergenerational equity considerations. Being aware of these weaknesses, the methods nevertheless provide additional information on the costs of resource depletion to decision-makers.

In contrast to the RCA, the TFP can consider the unpriced contribution of natural resource stocks and flows. This can be crucial with respect to variations in soil resilience.

However, RCA, PCA, and TFP are rather technical and data demanding. Methods that assess resource appreciation by the end user, e.g. willingness to pay/accept, hedonic pricing, or substitute evaluation, can be alternatives or valuable supplements, depending again on the objectives of the study. Some characteristics of these approaches are summarized in Table 7.

Finally, the CBA and MCA offer frameworks for a more complex impact assessment of nutrient depletion by integrating results from RCA, PCA, TFP or farmers' assessments. While CBA requires monetary values, MCA allows the integration of qualitative data, nonmonetary costs and benefits and other objectives than economic efficiency, thus offering the broader umbrella (cf. Figure 3). This may be especially important in developing countries, and in other situations where little quantitative information on the environmental impacts of nutrient depletion is available (Hanley and Spash, 1993). Table 8 summarizes key characteristics of both umbrella approaches.

Our case study on the economic assessment of soil nutrient depletion in SSA is based on the RCA and a range of assumptions mostly due to the aggregation of nutrient depletion data by Stoorvogel and Smaling (1990). Although these estimates are certainly crude, they have the advantage of using a uniform estimation method for all countries. The data can give decision-makers and economists a new assessment of the costs of resource depletion in SSA.

While compiling and processing biophysical data for our RCA case study we accepted major knowledge gaps at different levels that decrease the reliability of our and related assessments. These gaps concern among others:

- The process of upscaling biophysical data to the level at which public policy is formulated without losing the integrity of the data.
- The low attention to nutrient stocks and the dynamics of nutrient flows, i.e. temporal scales need to be defined considering local soil (fertility) redistribution as well.
- The lack of sufficient data on the dimension of soil nutrient replenishment under fallow in different climates.

The often requested adjustment for nutrient availability in the nutrient balance affects mostly erosion with relatively low amounts of available nutrients among the total amount considered in the nutrient balance. Our case study showed consequently that countries with high nutrient depletion rates through erosion, such as Malawi, are not automatically countries with high on-site nutrient depletion costs. The picture might change if erosion-related off-site costs are added.

Table 7. Application characteristics of different methods appropriate for the economic assessment of nutrient and carbon depletion.

Method	PCA	RCA	TFP	Substitute goods	Hedonic pricing	CVM
Advantage	Integrated approach: No need to consider different nutrients (or fractions) or certain SOM benefits. Particularly appropriate for erosion	Simple to apply, especially if nutrient balance data and fertilizer prices are available	Considers unpriced contribution from nutrient stocks and flows; values sustainability besides economic viability	Allows the use of implicit market prices or shadow prices	Integrated umbrella approach to soil fertility depletion	Some approaches are relatively easy to apply, i.e. farmer-oriented
Perspective	Farmers' income change	Also addresses intergenerational costs	Economic efficiency and sustainability	Perspectives of various users	Land markets	Farmers' point of view
Facilitation of interaction (participatory on-farm research)	Yes, in cases with obvious erosion and yield decline	No	No	Yes	In part	Yes

Table 7. cont'd.

Method	PCA	RCA	TFP	Substitute goods	Hedonic pricing	CVM
Monetary values used	Price of inputs and outputs	Market price of direct substitutes	Market prices as TFP index input	Implicit market prices	Land (rental) prices	Artificial market prices; contingent ranking: scores
Special data needed	Erosion loss; yield - soil loss function	Nutrient balance/ loss	Nutrient losses (or net balance)	Similarity analysis	Land (rental) prices	Respondents' characteristics
Shortcomings (examples)	Lack of *site-specific* nutrient depletion - yield functions (long term)	Not all nutrients are equally important	Mathematically demanding	Difficulty to find adequate substitutes	Low application potential in areas without land markets	Many sources of bias possible
Data demanding	High	High	High	Average	Average	Low - average

Table 8. Comparing various aspects of CBA and MCA.

Aspects	CBA	MCA
Alternatives	One is selected, which is compared in 'with' and 'without' situations.	Comparison of alternatives is essential feature.
Objectives	One, in terms of maximizing utility; others as constraints.	Various, of different nature (e.g. economic, ecological, social).
Criteria	Economic efficiency; in social CBA, also equity.	Various criteria, on basis of objectives.
Attributes	Costs and benefits, directly or indirectly in monetary terms.	Wide variety, quantitative or qualitative.
Procedures	One (standard) method, with well-established procedures.	Various methods, each with own procedures.
Type of data	Quantitative only.	Quantitative and/or qualitative; depends on method.
Currency	Monetary unit.	Scores on all criteria expressed in own unit.
Valuation	Prices (market/opportunity/ accounting prices). SCBA: shadow prices	Weights, reflecting subjective insights.
Discounting	Essential practice.	Not applied.
Off-site cost considered	Only in social CBA.	Yes.
Method sensitivity	The efficiency criteria (NPV/ IRR) normally give similar results.	Different MCA methods may give different results.
Cost of method	Requires detailed costs and benefits calculations.	Simpler MCA methods do not need much time.
cost effectiveness	Effective for large- and small-scale projects.	For small projects simpler methods can be chosen.
Past experiences	Often applied for environmental projects. Problems with method to assess benefits.	Not often applied yet in developing countries.
Appropriateness for participatory research	Only simple methods; interaction for data collection.	Simple methods facilitate interaction and participation.

Source: De Graaff (1996), modified.

With regard to a complex economic assessment of soil erosion, Enters (1998b) concluded that CBA provides a logical framework for the systematic collection, interpretation, and presentation of information from the perspective of trade-offs in decision making. The author also stresses that the final result should be presented in a comprehensible way to the different stakeholders concerned. Here some of the less sophisticated MCA methods might have a comparative advantage by including intangible costs and benefits giving more space to farmers' points of view. With regard to nutrient depletion, including soil erosion and SOM depletion, both approaches, CBA and MCA, offer a sound framework for an economic impact assessment and the appraisal and evaluation of soil and water conservation projects. The method(s) finally used will depend on the situation. The whole framework including the different impacts of nutrient and SOM depletion, on site as well as off site, and examples for their economic assessment, is illustrated in Figure 6. Some of the methods and pathways shown are mutually exclusive. For convenience, we also considered in the figure off-site effects related to erosion and sedimentation of sand or silt, i.e. not only nutrients and SOM, which might result in loss of dam capacity among other impacts. For the discussion of this broader impact, however, we refer again to Grohs (1994) and Enters (1998a).

Economic valuation techniques might help to assess the costs of nutrient depletion damages, but they cannot give an unambiguous answer on how much to invest in conservation. Ultimately, as Enters (1998b) sums up, it is the client of the analysis, whether a farmer, project manager, or policy-maker, who should be able to perform his/her own sensitivity analysis to examine what happens to the bottom line set by his/her own objectives and conditions.

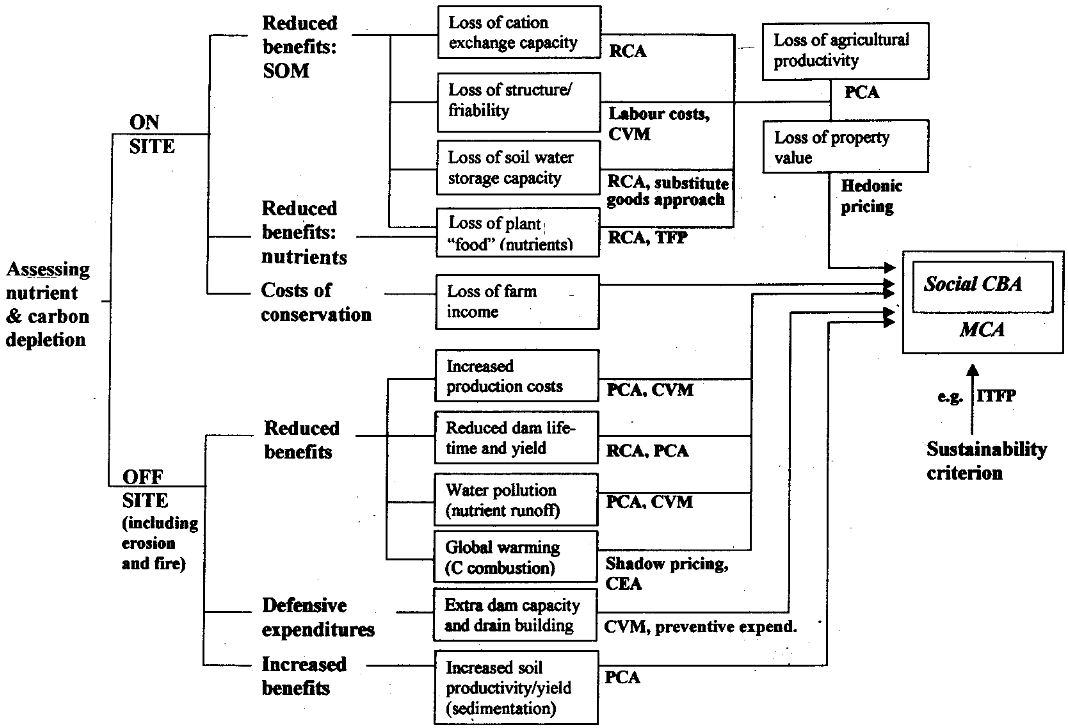

Figure 6. Framework for soil nutrient and carbon depletion: Impact and examples of methods for an economic assessment. Not all methods can be used at the same time to avoid double-counting.

Appendix 1

Calculating the price of depleted nutrients for the replacement cost approach

The calculation method used for the RCA was suggested by Pete Geurts. It is based on the fact that units of N, P_2O_5 and K_2O are not produced or sold at the same cost or price. A unit of phosphorus is far more expensive than a unit of N or K_2O. In order to express the cost of fertilizers in nutrient units rather than in product units, some idea of the cost or price ratio between these three macro-nutrients is needed. This might be the price of the raw materials to produce the fertilizers.

For example in Nigeria, mainly NPK blends and urea have been sold in the last few years and the prices of their raw materials reflect the price ratio among the three macro-nutrients (Table A1):

Table A1. International prices, June 1998 (source FERTECON).

Product	Ammonia	H_2PO_4	KCl
US$ ton^{-1}	140.0	276.8	94.7
Unit	N	P_2O_5	K_2O
Unit %	77.0	53.0	60.0
US$ kg unit^{-1}	0.18	0.52	0.16

The price ratio between the nutrients is shown in Table A2 taking, for example, the cheapest nutrient (K_2O) as the base:

Table A2

	N	P_2O_5	K_2O
Price ratio	1.2	3.3	1.0

If we express the cost per unit nutrient (N, P_2O_5 and K_2O) in K_2O price equivalents, then we obtain Table A3:

Table A3

Product	N	P_2O_5	K_2O	SUM	Price survey	Naira
	K_2O equivalents				Naira 100 kg^{-1}	K_2O eq^{-1}
15:15:15	17.3	49.6	15.0	81.9	2786.0	34.0
20:10:10	23.0	33.1	10.0	66.1	2604.0	39.4
20:10:10+10Ca	23.0	33.1	10.0	66.1	2470.0	37.3
25:10:10	28.8	33.1	10.0	71.9	2850.0	39.6
Urea	53.0	0.0	0.0	53.0	2710.0	51.1
Single super phosphate	0.0	59.6	0.0	59.6	2530.0	42.5
					Mean	40.7

90 naira = approx. US$1.00

Of each fertilizer type, the mean prices per 100 kg (to obtain correct % equivalents) are listed in Table A3. The last column provides the average cost per K_2O unit. The overall mean is given below (naira 40.7). With the nutrient ratios (Table A2), we can now also estimate the prices of one kg of N and P_2O_5 (Table A4), which has to be converted into, for example, US dollars.

Table A4

Mean retail prices, naira kg^{-1}	
N	46.9
P_2O_5	134.6
K_2O	40.7

This method was used to calculate the unit N, P_2O_5 and K_2O prices in 15 landlocked countries and seaboards in SSA on the basis of the fertilizer (including PR) available locally. The average nutrient price and its standard deviation (0.50 ± 0.10 US$ kg N^{-1}; 1.22 ± 0.20 US$ kg $P_2O_5^{-1}$, and 0.43 ± 0.06 US$ kg K_2O^{-1}) were suitable to estimate the margins for nutrient replenishing costs in countries not covered by the survey (Table A5) considering variations due to fertilizer type and transport distance[1]. The assessment does not consider fertilizer subsidies.

Table A5. Cost assessment of annual nutrient (NPK) depletion (Σ outputs – Σ inputs) in SSA on the basis of a 1998 fertilizer retail price survey and its relation to the agriculture share in GDP (AGDP).

Country	NPK depletion US$ (millions)	NPK depletion as % of AGDP
Angola	32 - 45	7 - 10
Benin	30 - 36	4
Botswana	< 1	< 1
Burkina Faso	72 - 85	8 - 10
Burundi	56 - 66	9 - 10
Cameroon	74 - 105	2 - 3
C.A.R.	11 - 15	2 - 2.5
Chad	34 - 48	6 - 9
Congo, Dem. Rep.	187 - 283	4 - 6
Congo, Rep.	6 - 9	2.5 - 4
Côte d'Ivoire	162 - 192	5.5 - 6.5
Ethiopia	328 - 378	10 - 11
Gabon	4 - 5	1
Gambia	6 -8	n.a.
Ghana	115 - 136	4 - 5
Guinea	26 - 37	2.5 - 3.5
Kenya	109 - 129	4 - 5
Lesotho	5 - 6.5	5 - 7
Liberia	13 – 19	n.a.
Madagascar	90 - 127	6 - 9

[1] There are of course other possibilities for retail price variations, such as a more cost-efficient mining of PR in SSA.

Table A5. cont'd.

Country	NPK depletion US$ (millions)	NPK depletion as % of AGDP
Malawi	84 - 99	9.5 - 11
Mali	72 - 85	5.5 - 6.5
Mauritania	3.5 - 5	1 - 2
Mauritius	< 1	< 1
Mozambique	105 - 148	17 - 23
Niger	140 - 197	18 - 25
Nigeria	770 - 909	5.5 - 6.5
Rwanda	69 - 81	13 - 15
Senegal	42 - 60	4.5 - 6.5
Sierra Leone	16 - 22	4 - 5
Somalia	38 - 53	n.a.
Sudan	196 - 276	n.a.
Swaziland	5 - 7	4 - 5.5
Tanzania	311 - 368	11 - 13
Togo	34 - 36	7
Uganda	202 - 284	7 - 10
Zambia	6 - 8	1
Zimbabwe	28 - 40	2.5 - 4
SSA	3922	7

The range considers price variations of available fertilizer types and transport. Nutrient depletion assessment for the year 2000 by Stoorvogel and Smaling (1990); fertilizer prices in 1998 from national sources in 15 representative SSA countries with the support of *Hydro Agri International*; calculation of US$ per kg nutrient following the procedure described above. Data are adjusted for nutrient availability assuming 5% available nutrients in eroded soil material. Assuming up to 10% did not change the costs (sensitivity analysis). The calculation is based on nonsubsidized fertilizer prices.

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