Integrating environmental and economic accounting at the farm level

Accounting for changes in the fertility of cultivated land

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Preface

Where farm record-keeping exists to calculate farm-household income, it commonly considers only financial accounts. Awareness of resource degradation or improvement calls urgently for a better understanding of the interrelations between environmental and socio-economic aspects in decision-making. Integrating calculations on resources deterioration/restitution in the financial accounts will help to determine differentiated productivity and efficiency of farming activities according to the applied technologies. Extended production cost and benefit calculations permit the formulation of technical recommendations that integrate economic and environmental factors in a clear and simple way for use by decision-makers and agricultural producers. Such recommendations should provide insights to farmers on how to improve, or at least to maintain resource availability and capability, making their livelihoods sustainable.

This report presents the conceptual aspects of a methodology for incorporating environmental analyses into a traditional accounting system at the farm level. The methodology accounts for changes in the quality and fertility of cultivated land and soil as an integrated input for calculating nutrient balances and farm income. The methodology has been designed by the Agricultural Support Services Division (AGS) at FAO and the *Royal Tropical Institute (KIT) of the Netherlands.*

This document is intended to provide a basis for understanding the different aspects involved in the application of the methodology. In this respect, it is complementary to the Operational Manual (Parts I and II), the case studies and the Excel spreadsheet, all of which are also included in this CD-Rom. The materials here presented were designed for the use of multidisciplinary teams consisting of soil scientists, agricultural economists and extension agents.

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Acknowledgements

The preparation of this document involved the participation of numerous persons, among them experts, research institutions and farmers. The methodology was designed by Felix Moukoko, AGS-FAO and Floris van der Pol, The Royal Tropical Institute, of the Netherlands.

In the validation and improvement of the methodology, there was participation by researchers from a number of National Institutes. In Thailand, we had the cooperation of the International Board for Soil Research and Management (IBSRAM) and the Ubon Ratchathani Rice Research Centre (URRC), from the Ministry of Agriculture. In Colombia, there were contributions from a team lead by Irma Baquero, of the National Corporation for Agricultural Research (CORPOICA) from the Ministry of Agriculture. In Costa Rica, there has been the collaboration of a team lead by Alvaro Chaves from the Department of Central Agriculture Conservation, the Research Department, and the Bureau of the Central-Eastern region from the Ministry of Agriculture. Additionally, numerous farmers participated in the data collection, providing information on farm management

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Summary and overview

Farm production, especially on small farms in many developing countries, is heavily dependent upon biological and mineral inputs drawn from the environment. Soil mining and erosion are key issues in those agricultural production systems. Overall pace of soil degradation has accelerated in the past 50 years, with highly visible 'hot spots' identified throughout the developing world.

In spite of the widespread impact of degradation, conventional economic analysis of farming systems continue to largely ignore costs associated with the depletion of natural resources, as well as pollution and other environmental impacts of farmers' actions. Estimates of farm income based on conventional farm and cost accounting fall short at least in three respects: (i) little attention, if any, is given to the contribution natural resources make to food and agricultural production; (ii) the impact of agricultural production on the environment is not taken into account; and (iii) the concept of depreciation, maintenance or replacement is not applied to natural environment capital.

These distortions conceal both the negative impact of agricultural production on the environment and the contribution of nature and environment to production processes and livelihoods. As a consequence, policies and measures in the agriculture sector - taken with the intention of defending the environment - often fall short of what will be required if the natural environment is to continue to provide food, feed and fibres for the present and into the future.

A critical underlying problem appears to be failure of the market mechanism to provide an account of the nature and value of nutrients being harvested and eroded from the soil. A system of information on the status and issue areas of soil depletion is required to make both the policy makers and the users aware of the dangers of inadequate management practices and policies. Two basic actions are required to this end: development of an accounting system providing a quantitative and monetary status of nutrient inflows and outflows in relation to specific ecological areas and farming systems; and development of a framework linking nutrient accounts in physical and monetary terms with conventional socioeconomic accounts of the farm economy, for combined micro-analysis.

Integrating calculations on resources deterioration or restitution in the financial accounts will help to determine differentiated productivity and efficiency of farming activities according to the applied technologies. Extended production cost and benefit calculations permit the formulation of technical recommendations that integrate economic and environmental factors in a clear and simple way for use by decision-makers and farmers. Such recommendations should provide insights to the farmers on how to improve, or at least to maintain resources availability and capability, making their livelihoods sustainable.

A methodology that seeks to integrate changes in land quality into economic farm accounts has been designed by the Agricultural Management, Marketing and Finance Service (AGSF), Agricultural Support Systems Division, FAO and the Royal Tropical Institute (KIT), the Netherlands. The methodology accounts for changes in the quality and fertility of cultivated land and soil as an integrated input for calculating nutrient balances and farm income. The objective of the methodology is to set up accounts that will accurately reflect real sustainable income at the farm level as well as to measure the financial contribution of land resources assets.

At the presently neglected micro- and meso-operational levels of farms and cropping systems, the methodology developed should facilitate improved accounting of the changes in natural capital. Major expected effects and impacts include better identification and characterization of sustainable farm income; improved decision making, planning and design of relevant defensive policies regarding sustainable natural resource management and environmental protection; and due weight given to environmentally friendly technologies, land use plans, farm plans and projects.

The tool used in this methodology to quantify changes in soil fertility is the balance of nutrient flows. Maintenance of soil fertility is determined to a large extent by the degree to which nutrient 'outflows' (uptake by crops plus losses due to processes such as leaching, erosion, volatilization and denitrification) are balanced by `inflows' (supplied by e.g. fertilization and weathering of soil minerals). If over a period of time the balance is negative (outflow exceeds inflow), this indicates that nutrients are being mined from the soil. It is critical in establishing nutrient flows to know what farmers actually do. This is then combined with understanding of natural processes to produce realistic results.

The methodology has been designed for use in conditions where soil nutrient mining is a key issue. Application of the method under nutrient surplus conditions is possible and may provide very useful information on the fate of nutrients under farming systems. Special precautions however are required with interpretation of the economic results. In those conditions valuation through fertilizer prices is not relevant. As the effects are mainly external, they should be treated as pollution, and included as such in integrated accounting systems.

A wide range of valuation techniques is available to measure actual value to users of environmental goods or services. Valuation methods such as the Replacement Cost Method (RCM) and Change in Productivity Method (CPM) are generally used to assess in fiscal terms, the benefits and costs related to changes in the value of the soil. For analyses of nutrients specifically, the RCM has an obvious advantage in that it is tied directly to the nutrients themselves and that it is simple to apply once net nutrient losses or gains are known, since market prices for key nutrients are usually available. In the context of the present study, the systematic use of the replacement cost method is suggested as a basic approach.

A procedure has been developed to integrate changes in the quality of land in current accounting. The purpose is to present data in meaningful formats in order to enable integration of environmental and natural resource use considerations into economic policy and decision making. Integration of environmental and economic accounting can be done in two ways: integration by addition of satellite accounts and integration by new line entries. Integration by addition is the first and necessary step of the change in the quality of the soil accounting development and integration process. Structural integration involves transferring the outcomes of such computation in a limited number of entries from the newly established nutrient to conventional accounts.

The resulting integrated balance sheet and operating statement provide a more comprehensive and accurate measure of the performance of and value added created by the business during an accounting period; enable the user to better assess the net capital formation and retained earnings; introduce into the analysis of farm business assets the concept of fixed capital consumption and its replacement allowance as a condition for ensuring sustainability in land use and productivity; help ensure that natural assets are treated in the same way as human-made assets; enhance the notion of sustainability standards into the concept of integrated accounts, already inherent in conventional farm income accounting; and allow for the establishment of a variety of ratios and indicators useful for integrated farm business management.

Analysis of outcomes of the calculated physical and monetary accounts may provide insight both on sustainability issues and on conventional nutrient efficiency and fertility management. Two types of analyses can be carried out: analysis of the internal structure of the nutrient accounts and analysis across the accounts coupled with the Integrated Balance Sheet and Operational Statement Analysis.

An analysis of the internal structure of the nutrient accounts can be an important step in assessing the strength and weaknesses of soil nutrient management and, therefore, of soil use and fertility management. The nutrient flow balance sheet shows the origins of soil nutrients used for crop production (inflows) and what such nutrients are used for (outflows), in physical or monetary terms; the impact of a particular production system and its cultural setting on the quality of the soil; the extent of soil mining associated with the production process; the real value added of agricultural production; explicit measures of negative or positive nutrient balances, comparing inflows and outflows; and ways to prevent soil mining.

Analysis across the accounts coupled with the Integrated Balance Sheet and Operational Statement Analysis can be carried out based on integrated indicators. These could focus on sustainability as well as on conventional farm management efficiency. A number of ratios and indicators can be calculated and analysed: the sustainability ratio (SR); added value with respect to nutrients (AVN); productivity foregone and replacement cost ratio (PRR).

The implementation of the methodology involves various steps such as collection of biophysical and socio-economic data; data entry and processing preliminary calculations; preliminary analysis of the outcome; verification and validation of data; and analysis of outcome. Analytical outcomes of the case studies conducted in Colombia, Costa Rica, Thailand and Bangladesh have been presented.

Participatory approaches offer a creative move to investigate issues of concern to people, and to plan, implement, and evaluate development activities. Soil fertility management is particularly suited to this type of collaborative interaction and learning. Popular methodologies for soil fertility management based on participative methods include Participative Learning and Action Research (PLAR). The principles, planning and design of soil fertility management strategies and implementation and evaluation aspects of the strategies as components of PLAR have been dealt with. The farmers' involvement in the application of methodology is sought through their views while collecting the information relating to farming practices, cropping systems and economic accounting, as a part of the participatory process. There is further scope for incorporation and integration of various elements of the PLAR process in the evolved methodology.

As an important step in the development of the methodology, pilot studies have been undertaken in Colombia, Costa Rica, Thailand and Bangladesh. These aimed at implementing, assessing and verifying the applicability, usefulness and effectiveness of the methodology. The findings of the case studies have demonstrated the appropriateness and effectiveness of the method as a framework for accounting for the contributions of the land to agricultural production; a tool to assess efficiency and productivity in soil resources management and farming systems; a tool for assessing feasibility of current conservation technologies; and a decision-support tool for land and development programmes.

In their present state, the operational procedures, guidelines and the integrated computer workbook related to the methodology are credited already quite accessible and effective. However, there is always scope for further improvement and efforts to make the information more easily accessible to the stakeholders and users.

The publication will be of interest to the various stakeholders such as farmers, soil scientists, agronomists, agricultural economists, and extension workers who are directly concerned with assessment of soil productivity, estimation of the financial contribution of land resource assets and appraisal of real sustainable farm incomes.

1. Introduction

The overall pace of soil degradation has accelerated in the past 50 years, with highly visible 'hot spots' identified throughout the developing world (Scherr and Yadav 1995). The cumulative productivity loss for cropland from soil degradation over the past 50 years is estimated to be about 13 per cent (Oldeman 1998).

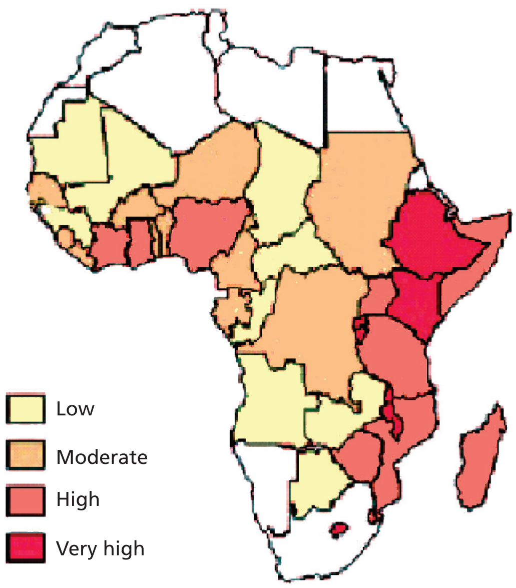
Farm production, especially on small farms in many developing countries, is heavily dependent upon biological and mineral inputs drawn from the environment. Soil mining and erosion are key issues in those agricultural production systems. Productivity of some soils in Africa has declined by 20 percent due to soil erosion and desertification (Dregne 1990). Yield reductions in Africa due to past soil erosion may range from 2 to 40 percent, with a mean loss of 8.2 percent for the continent. If accelerated erosion continues unabated, yield reductions by the year 2020 may be 16.5 percent (Lal 1995). Annual reduction in total production for 1989 due to accelerated erosion was 8.2 million tonnes (Mt) for cereals, 9.2 Mt for roots and tubers, and 0.6 Mt for pulses (Lal 1995). There is no indication that the situation has much improved since then. There are also serious (20 percent) productivity losses due to erosion in Asia (Dregne 1992). In South Asia, annual loss in cereal production caused by water erosion is estimated to be 36 Mt, equivalent to US$ 5400 million, with a further $1800 million loss due to wind erosion (Young, 1994). The total annual cost of erosion from agriculture in the USA is estimated to be about $ 44 billion per year, about $ 247 per hectare of cropland and pasture. Globally, the annual loss of 75 billion tonnes of soil (at $ 3 per tonne of soil for nutrients and $ 2 per tonne of soil for water) constitutes a cost to the world of about $ 400 billion per year, or more than $ 70 per person per year (Pimentel *et al.,* 1995).

Estimates for 38 countries in sub-Saharan Africa (Figure 1) suggest that annual net loss of nutrients per hectare during the 1980s was 22 kg N, 2.5 kg P and 15 kg K, representing about US$ 10/ha annually (Smaling 1993). Economic costs of nutrient losses (N, P and K) by soil erosion in Zimbabwe were estimated by Stocking (1986). The annual losses of N and P alone totalled $ 1.5 billion. In South Asia, annual economic loss is estimated at $ 600 million for nutrient loss by erosion, and $ 1200 million due to soil fertility depletion (Young, 1994). Soil nutrient depletion is a significant problem in Latin America, where average annual nutrient depletion exceeds 50 Kg/ha (Wood *et al.*, 2000).

It is clear that crop production in many regions involves depletion of the mineral nutrient stock of the soil, with implications of declining yields. Measures to improve or sustain soil fertility, replacing depleted nutrients, are essential for achieving higher production goals. Technologies based on assessment of system sustainability deserve consideration in this context.

Conventional economic analyses of farming systems continue to largely ignore costs associated with the depletion of natural resources, as well as pollution and other environmental impacts of farmers' actions. Estimates of farm income based on conventional farm and cost accounting fall short at least in three respects: little attention, if any, is given to the contribution of natural resources to food and agricultural production; the impact of agricultural production on the environment is not taken into account; and the concepts of depreciation, maintenance or replacement are not applied to natural environment capital.
To a large extent, such environmental inputs are in effect valued at zero; yet the associated

FIGURE 1
Nutrient depletion rates in sub-Saharan Africa, 1983



Source: Roy *et al.*, 2003.

output is measured and valued at prevailing market prices. Therefore the farm income suggested by existing farm accounting methods is not only inaccurate, but also unsustainable – with consequences for the agriculture sector as a whole as well as for the national accounts.

These distortions conceal both the negative impact of agricultural production on the environment and the contribution of nature and environment to production processes and livelihoods. As a consequence, policies and measures in the agriculture sector –taken with the intention of defending the environment– often fall short of what will be required if the natural environment is to continue to provide food, feed and fibers for the present and into the future.

The challenge

To help address these issues, Agenda 21, the Plan of Action of the United Nations Conference on Environment and Development held in Rio de Janeiro in 1992, urged that conventional accounting systems should be expanded to cover concerns related to sustainability. In response, the United Nations Statistics Division issued a Handbook on a System of Integrated Environmental and Economic Accounting (United Nations 1993, 2000).

The System of Integrated Environmental and Economic Accounting (SEEA) handbook is basically a macroeconomic framework. It focuses on the measurement and valuation of environmental and economic relations at national level. Defining modules that break down into micro-economic production units and their environmental impacts is left for further research and studies: a pressing challenge. Since the ecological balance and sustainability are also at stake at the level of the farm and community, the need seems even more pressing to attempt similar adjustments at these levels, to allow assessment of what could be termed an environmentally adjusted farm income.

The development of such integrated environmental and economic accounting modules was long constrained by the lack of reliable methods for measuring and valuing environment and natural resources services. This situation has changed dramatically in recent years. Significant advances have been made in accounting for basic natural resource and physical environmental processes and in processing the relevant data. Furthermore better basic natural resource and environmental statistics have become available.

Objectives

The present publication contributes to the development of practical procedures by the Food And Agriculture Organization of the United Nations (FAO), the Royal Tropical Institute (KIT, Amsterdam), and cooperating partner institutions in various countries, that will make it possible to respond to the challenge mentioned earlier. In this light the two main objectives are:

- to develop guidelines for establishing nutrient inflows and outflows related to on-site soil mining, erosion and recovery, measuring the relevant indicators both in physical and in monetary terms;
- to develop an integrated environmental and economic accounting framework that incorporates the value of the services provided (or damages caused) by the flow of nutrients into conventional farm accounts.

The methodology developed in the following chapters should facilitate improved accounting from the point of view of natural capital at the presently neglected micro and meso operational levels of farms and cropping systems. Major expected effects and impacts include:

- better identification and characterization of sustainable farm income;
- improved decision making, planning and design of relevant defensive policies regarding sustainable natural resource management and environmental protection;
- due weight given to environmentally friendly technologies, land-use plans, farm plans and projects.

Approach

The methodology has been developed in a step-by-step approach, each step involving participation of different partner organizations. Five major steps have been included:

i. review of literature and knowledge, providing a concise but comprehensive background on the relevant state of the art;
ii. development of a methodology and operational procedures for establishing accounts related to soil mining and erosion;
iii. development of an on-site integrated environmental and economic accounting framework incorporating nutrient flow indicators into conventional farm accounts;
iv. implementation of case studies of integrated accounts as a means of testing the appropriateness, usefulness, applicability and cost-effectiveness of the integrated accounting framework and the availability of the required data;
v. internal and external review of the study outputs and subsequent publication of the methodology and guidelines.

Steps i – iii have been completed mainly by FAO and KIT, with participation of the International Institute for Environment and Development (IIED). Step iv is completed, with case studies implemented in Bangladesh, Colombia, Costa Rica and Thailand. In addition to their role as test exercises, case studies would, *inter alia*, help familiarize national staff with the concept and methods of integrated accounting and assist in setting up coordinating mechanisms for the integration of data from different subject areas. In step v the results have been reviewed internally by FAO, KIT and partner institutions, and will be reviewed externally by other interested bilateral and multilateral partners.

Contents of the publication

This publication presents the framework of the proposed methodology. Chapter 2 deals with the place of soil mining and erosion in agricultural production and Chapter 3 with the methodology for physical quantification of these degradation processes. Valuation issues related to soil mining and erosion are treated in chapter 4. Chapter 5 describes the proposed on-site integrated accounting structure. The analytical approach and implementation aspects are dealt with in Chapter 6. Chapter 7 describes participative methods for soil fertility management and application of the methodology to national programmes. Conclusions and recommendations have been presented in Chapter 8.

2. Conceptual framework

SCOPE OF THE METHOD: SOIL NUTRIENT MINING AND RECOVERY

In many parts of the world, agriculture has been going through a transition from fallow-based systems to more permanent farming. Traditionally, plant nutrients needed for agricultural production were provided "free" by natural processes such as weathering, deposition by rain and dust, deposition of sediments in flooded systems, and biological fixation. These processes produce a steady inflow of nutrients, which were collected and stored in the soils and in the natural vegetation during fallow periods. The accumulated nutrients allow for a generally short (2–3 years) cultivation period with an acceptable production level. Fallow periods also help in restoration of soil physical properties and soil organic matter, which in turn lead to reduced runoff and erosion.

Traditional shifting cultivation with long fallow periods sustained low but relatively stable production of food crops. Production levels, averaged over the complete cycle of fallow and cultivation, were low: in West Africa generally less than about 200 kg/ha grain per year (e.g. three years with 800 kg grain/ha followed by 9 years of fallow). As long as the agricultural production in such a cycle remained below the level that could be maintained by the freely provided nutrients, agriculture was sustainable.

In many areas, fallow periods are being reduced and farmers are increasingly cultivating marginal lands, susceptible to various forms of degradation. With increasing population density and pressures on land, shifting cultivation is disappearing. Long-term fallows, which accomplished the task of natural recuperation in the past, need to be replaced with (or adapted to) appropriate integrated systems. These include fertilizers or other effective nutrient sources, as well as no-till (or mulch tillage), cover crops, and rotations or agroforestry practices based on sound agro-ecological principles, taking advantage of natural restorative processes (Weight and Kelly 1999). However, the intensification of agriculture in small land holdings, especially in Africa, typically has not been accompanied by adequate nutrient inputs to compensate for the outputs through crop harvests and losses, leading to soil degradation through processes such as soil nutrient mining and soil erosion.

When fallow periods become shorter (and cultivation periods become longer), the resulting increase in production during the cycle beyond the sustainable "free-inputs" production level requires extra nutrients. These are to be paid for in cash or labour or are mined from the soil nutrient reserve. This transition typically results in poor soils and poor farmers: poor soils because rural societies are not accustomed to setting aside sufficient funds for maintenance of soil fertility, and poor farmers because declining yields and higher costs of soil fertility maintenance will affect their income.

The characteristics of such a transition period are not unique to tropical countries. A study of the transition of fallow-based agricultural systems to permanent systems in Flanders (Belgium) around 1700 shows that farmers searched intensively for materials that could prolong the use of their fields. In addition to manure, shells, seaweed, marl, mud from city canals, bones and blood became sources of agricultural nutrients. The huge quantities required forced farmers to invest heavily in labour and transport. They are reported to have spent over 45 percent of their gross income on maintaining fertility of their soils (Slicher van

Bath 1977). Long-term trials in southern Mali have shown that a sustainable cotton rotation can be obtained with an investment of about 40 percent of farmer income in soil fertility maintenance. In practice, however, only about 20 percent is invested, while in the region as a whole only about 10 percent is invested in maintaining soil fertility (Van der Pol 1992).

The exploitation of free, renewable, nutrients in agriculture may have been the reason for classifying agriculture as a part of the primary sector, but this argument holds only as long as the supply of these free nutrients is sufficient for production. When additional nutrients must be bought at market prices, or can only be obtained by additional labour inputs (as is the case when organic manure is used), it would be more realistic to consider agriculture a part of the secondary sector, with industrial activities. At present, agriculture in many countries can be seen as moving away from being a primary sector system, with free access to finite resources, and towards a system that is a part of the secondary sector, transforming plant nutrients and other inputs into products.

Such a transition requires not only changes in technology, but also drastic changes in the economic and legal context (Lele and Stone 1989). The readiness of farmers to invest in nutrients will depend not only on observable changes in yields in response to added nutrients, but also on factors such as land tenure systems and the ratio between input and output prices.

As long as the conditions required for a transition are not met, farmers will continue to depend on soil nutrient reserves to provide an important fraction of their income (Van der Pol 1992). In many countries of sub-Saharan Africa less than half of the total quantity of nutrients used for agricultural production is returned by natural inflows and applications of fertilizer and manure (estimated from data presented by Stoorvogel and Smaling 1990). Correcting nutrient deficits will not be easy, and will require significant modifications in existing farming practices. The methods presented in this publication aim to assist decision-makers in creating a policy environment and infrastructure that enable these modifications.

Related natural and human-induced processes

Soil mining is the process by which farming removes more nutrients from the system than are replaced. It is associated with low-input agriculture in which “free” nutrient inflows and organic amendments with generally low nutrient value are used – these are insufficient to replace nutrients extracted by crop harvests and lost by erosion or leaching.

In fact, erosion and soil mining are tightly intertwined. The actual process of soil mining leads to a gradual decline in the organic nutrient reserve of the soil. This decline increases the sensitivity of the soil to erosion. erosion in its turn accelerates nutrient depletion because finer particles –which contain more organic matter and nutrients– are lost; leaving behind a soil skeleton that has become relatively poorer (Roose 1981).

Soil erosion is a natural process, but is often dramatically accelerated by human activities. Especially where rural residents have no option but to cultivate marginal areas with poor and shallow soils, with sloping land or forest frontiers of uplands, agriculture can be a main cause of soil erosion and watershed deterioration. Cultivating uplands often leads to a reduction in natural soil fertility and crop productivity, undermining the potential for income generation in the future.

The Sahelian region suffers from severe wind erosion during the dry season and accelerated gully erosion during the much-awaited rains. In Africa north of the equator, 11.6 percent of the total land area is affected by water erosion. High erosion rates are especially prevalent in the coastal regions of northwest Africa. Gully erosion is catastrophic in some parts of southeastern Nigeria. Soil erosion is also severe in southern Africa wherever large-scale farming is practised without appropriate conservation measures. (Lal 1990). Soil erosion and soil nutrient depletion are critical problems as well in the highlands of East Africa, for example. Ethiopia is among the sub-Saharan Africa countries with the highest rates of soil nutrient depletion. FAO (1986) estimated that 50 percent of the arable lands in the Ethiopian highlands are moderately to severely eroded. Estimates of the annual costs of erosion in the Ethiopian highlands range from US$[1] 1.8 to 25 million per annum (0.05 to 0.7 percent of agricultural GDP); the estimated gross discounted present value of cumulative losses caused by erosion ranges from US$ 550 to 1300 million (Bojo and Cassells 1995).

In Mexico, total annual costs to the economy of soil erosion are estimated at $1 billion (Margulis 1992). Soil erosion is the most important aspect of soil degradation in the tropical hillside agro-ecosystems covering the Andean region and Central America. Intensive hillside cultivation employing traditional methods leads to accelerated loss of fertile topsoil. Productivity losses caused by erosion as high as 20 percent have been reported for Asia. In south Asia, annual production losses due to water erosion are estimated at 36 million tons of cereal with an equivalent value of US$5.4 billion, and losses due to wind erosion at $1.8 billion. The estimated annual cost of erosion to agriculture in the USA is about $44 billion, about $247 per hectare of cropland and pasture per year. On a global scale the annual loss of 75 billion tons of soil costs the world about $400 billion per year, or more than $70 per person per year (Eswaran *et al.*, 1999; Anecksamphant *et al.*, 1999).

It is apparent that soil erosion is causing substantial costs to agriculture. These problems are contributing to low agricultural productivity, poverty and food insecurity and malnutrition in the highlands. The technological response to soil erosion and nutrient depletion is adoption of effective erosion control measures and improved soil fertility management technology, principally use of inorganic fertilizers. In the absence of technological response, poor smallholder farmers respond by cultivating more land to compensate for low crop yields (Jabbar *et al.*, 2000).

Solutions that allow erosion control and prevention of soil mining are as tightly intertwined as the phenomena themselves. Labour requirements for erosion control measures are high; such investments are not easily made profitable on mined soils (Stocking 1986; Stocking and Abel 1989). Yet controlling erosion would in many cases be a more cost-effective way to maintain soil fertility than applying fertilizer. The cost-effectiveness of erosion control in terms of nutrients depends on the intensity of cultivation: the more nutrients are used by the crops, the more erosion control pays. This is one reason for reported failures of erosion control programmes in low-input areas (IFAD 1986).

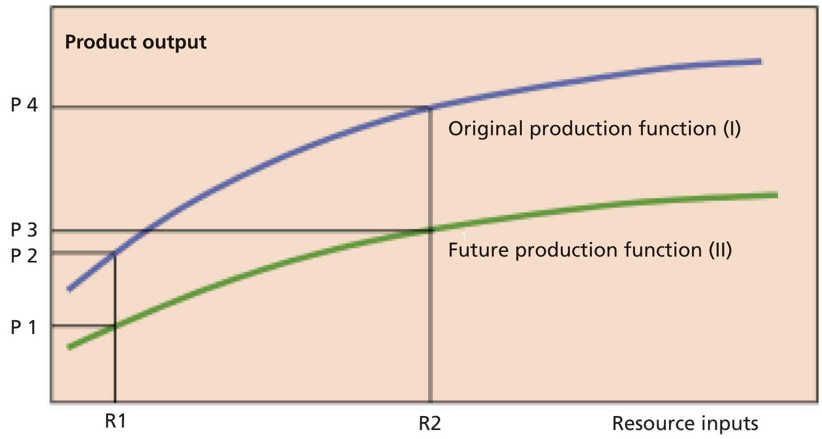
Economic consequences of soil mining and recovery

With constant production techniques, soil mining and erosion lead to declines in production over time. The implications of this are illustrated in Figure 2.

Over a single time period, there has been a downward shift from production function (I) depicting the original input/output relationship, to production function (II), characterizing the relationship at the end of the time period. To the original input of resources R1 corresponds an output of P2. An equal application of resources in the future will not result in an output of the original magnitude. R1 will result only in P1, smaller than P2. If the original

[1] At 5.42 EB per US$ (rate in January 1995)

FIGURE 2
Evolution of production with soil mining and erosion



Source: Moukoko and Van der Pol, 1999.

input of resources is increased from R1 to R2 (after the fall to II), it will result in output not of P4 (production function I) but only of P3.

This change in the relationship between resource inputs and the resulting product output over a single time period defines the concern and challenge of soil conservation in general and, in particular, that of soil mining and erosion. It underscores the need for preventing and repairing the damage to the soil by soil mining and erosion. Preventing soil mining and controlling erosion have costs and benefits, the far-reaching implications of which can be assessed adequately only if they are expressed in monetary values. Once established, these values can be used for various purposes: as indicators of sustainability for current farming systems, for assessing the environmental impact of agricultural investment projects, as key elements of sound environmental defensive policies at farm, community and national levels, and for assessing the efficiency of soil conservation measures and technologies.

Shortcomings in taking nutrient flows into account

Soil nutrient depletion poses a critical problem for agricultural production. Over decades, in Africa small-scale farmers have removed large quantities of nutrients from their soils without using sufficient quantities of manure or fertilizer to replenish the soil. The case of sub-Saharan Africa appears particularly alarming. Annual nutrient removal by crops and erosion-induced loss of nutrients far exceed their rate of replenishment. Estimates for 38 countries in sub-Saharan Africa suggest that annual net loss of nutrients per hectare during the 1980s was 22 kg nitrogen (N), 2.5 kg phosphorus (P), and 15 kg potassium (K), representing about US$10/ha annually (Smaling 1993; Weight & Kelly 1999).

The annual nutrient deficit for a cotton–maize–sorghum rotation in southern Mali was estimated to be about 28 kg/ha N, 18 kg/ha K and 35 kg/ha lime (Van der Pol 1992). Studies show that 65 to 75 percent of these deficits are through harvest and removal of crops and residues (biomass) and by erosion.

Estimated average nutrient losses for Ethiopia were more than 80 kg of nutrients per hectare in 1983 (including 41 kg N, 5.7 kg P and 25.7 kg K), among the highest rates of depletion in sub-Saharan Africa, and were predicted to be even higher by the year 2000

TABLE 1
Total annual nutrient balances for Ghana, Kenya and Mali

Country	Nutrients (kg/ha)		
	N	P	K
Ghana	- 27	- 4	- 21
Kenya	- 38	0	- 23
Mali	- 12	- 3	- 15

Source: FAO 2004

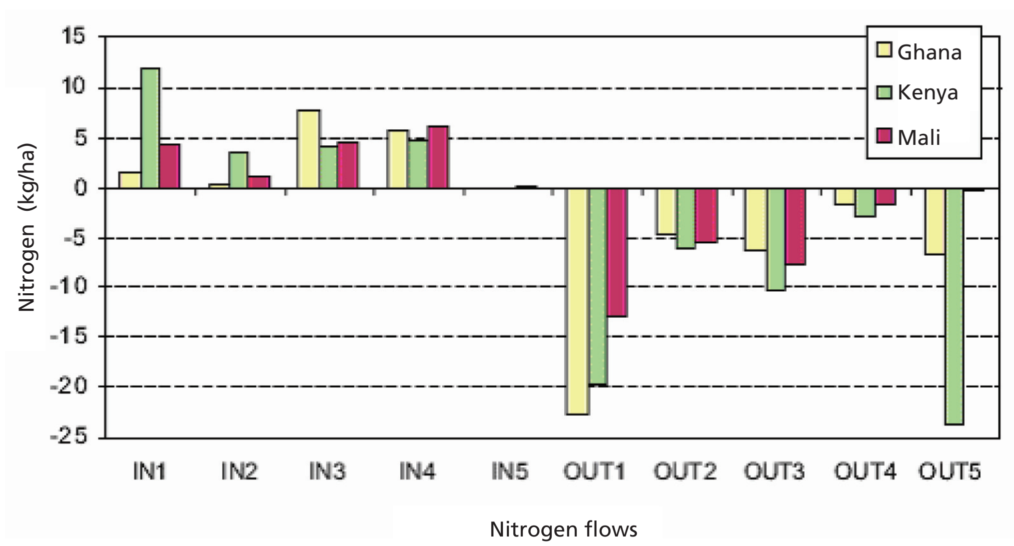
(Stoorvogel & Smaling 1990). The main cause of nutrient outflow is soil erosion (about 60 kg/ha), followed by removal of harvested products and crop residues; inflows from manure and mineral fertilizer are very low (averaging less than 10 kg/ha). Other causes of soil nutrient depletion include limited recycling of dung and crop residues in the soil, declining fallow periods, organic matter burning. Although the farming system in Ethiopia is primarily mixed crop-livestock, nutrient flows between the two are predominantly one-sided: UNECA (1996) data show that even though almost all households (90 percent) fed crop residues to their livestock, only 40 percent returned manure to their farmlands.

A recent FAO study undertaken in Ghana, Kenya and Mali confirms the severity of the nutrient depletion problem (FAO 2004). Table 1 shows that all three countries suffer from negative nutrient balances.

Figure 3 highlights the different nutrient flows in the countries, and shows that erosion is the main cause of the negative nutrient balance for Kenya.

The need to maintain the productive capacity of the soil is imperative. In some cases the value of all the nutrients needed for production, including those provided by the environment, is higher than the value of the product (Van der Pol *et al.*, 1994). In such cases, agricultural production has a negative added value, calling its existence into question as degradation could be carried to the point of irreversible loss. The transformation of

FIGURE 3
Overall nitrogen flows for Ghana, Kenya and Mali



Source: FAO 2004
Note: IN1 mineral fertilizer; IN2 manure; IN3 deposition; IN4 biological N fixation; IN5 sedimentation; OUT1 harvested products; OUT2 crop residues; OUT3 leaching; OUT4 gaseous losses; OUT5 erosion.

agricultural land into non-arable eroded glacis in the Keita area, Niger is a good case in point. Agricultural production produces a positive rent, which could be used to maintain the productive capacity of the soil in a sustainable manner. However, this rent or part of it often is not invested back into the land. In fact, the value of output derived from soil nutrients is accounted for but not the decline in the output-generating capacity –capital consumption– because of their removal.

A critical underlying problem appears to be failure of the market mechanism to take into account the nature and value of nutrients being harvested and eroded from the soil. Because they are not traded in the market, the value of such nutrients is not adequately reflected in conventional economic accounts and analyses. The higher total costs of avoiding or repairing the damages associated with their removal are not considered either. In fact, under conventional farm accounting, the value of such seemingly "free" inputs is implicitly estimated to be zero. Government policy failure and inadequate institutional arrangements relevant to promoting sustainable soil maintenance and management are other critical gaps. Existing fiscal instruments –taxes and subsidies– often result in overexploitation and depletion of natural resources, including land.

The need to bridge the identified gaps can hardly be overstated. A system of information on the status and issue areas of soil depletion is required to make both the policymakers and the users aware of the dangers of inadequate management practices and policies. Two basic actions are required to this end: (i) development of an accounting system providing a quantitative and monetary status of nutrient inflows and outflows in relation to specific ecological areas and farming systems, and (ii) development of a framework linking nutrient accounts in physical and monetary terms with conventional socio-economic accounts of the farm economy, for combined micro-analysis. The present work is a contribution to ongoing efforts in that direction.

3. Quantifying nutrient flows

The tool used in this study to quantify changes in soil fertility is the balance of nutrient flows. Maintenance of soil fertility is determined to a large extent by the degree to which nutrient outflows (uptake by crops plus losses due to processes such as leaching, erosion, volatilization and denitrification) are balanced by inflows (supplied by e.g. fertilization and weathering of soil minerals). If over a period of time the balance is negative (outflow surpasses inflow), this indicates that nutrients are being mined from the soil.

Erosion involves changes in the quality and quantitative availability of topsoil. An important aspect of decline in the quality of land can be described in terms of nutrient depletion associated with the loss of such topsoil. Another aspect is the reduction in nutrient storage capacity. In the present context, the impact of soil erosion is established in terms of the quantities of sediment lost and the nutrient content of the sediment. The impact of both soil mining and erosion is thus accounted for as depletion.

In the following sections a short description is given how the various nutrient flows can be calculated. It is critical in establishing nutrient flows to know what farmers actually do. This is then combined with understanding of natural processes to produce realistic results. The procedures are designed to require only basic mathematical operations. Since precision is low, introduction of more complicated mathematical functions, although technically feasible, would burden the system to no purpose. A spreadsheet workbook is provided to organize data and make quick estimates possible.

WHAT ARE NUTRIENTS?

Plants need food for their growth and development. They have the power of building up organic tissues directly from inorganic materials. Plants live, grow and reproduce by taking up water and mineral substances from the soil, carbon dioxide from the air and energy from the sun to form plant tissues. From a limited number of mineral elements, drawn from the soil and the air, plants synthesize a vast array of products. These mineral elements are known as plant nutrients. Sixteen nutrient elements are recognized as being essential to plants for their normal growth and development. These are carbon, hydrogen and oxygen, which are derived from the air and soil water, and nitrogen, phosphorus, potassium, calcium, magnesium, sulphur, iron, zinc, manganese, copper, boron, molybdenum and chlorine, which are supplied by the soil in varying quantities either from the reserves in the soil or through application of manures and fertilizers.

Nitrogen, phosphorus and potassium, the major or primary nutrients, are used in large quantities by plants. Calcium, magnesium and sulphur, the secondary nutrients, are required in relatively smaller but in appreciable quantities. Micronutrients such as iron, zinc, manganese, copper, boron, molybdenum and chlorine are required by plants in small quantities for their growth and development.

A productive soil should contain all the essential plant nutrients in sufficient quantity and in balanced proportion. Each of the essential nutrients has a definite and specific function to perform in the growth and development of plants. A deficiency of any of them inhibits plant growth to its full potential. Replenishment of soil nutrients depleted through cropping and processes such as soil erosion, leaching and gaseous losses assumes importance in this context.

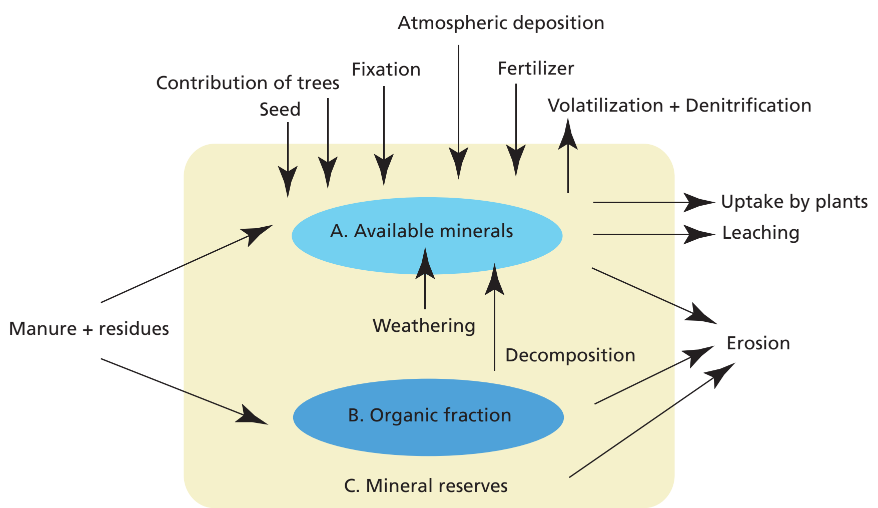
Only part of each mineral element in soil is available to plant growth. A large proportion of major elements necessary for plant growth, such as potassium and phosphorus, forms part pf the structure of soil minerals. Nutrient balance studies deal with this issue in various ways. Many nutrient balance studies (e.g. Stoorvogel & Smaling 1990) determine total nutrient balances, thus considering all N, P or K present in the soil as nutrient. This might be the easiest approach, but it has two main disadvantages. Weathering of soil minerals is not accounted for, since the liberated nutrients were already present in the soil. The results of this method are remote from the perception of farmers, who regard fallow periods –during which weathering provides the soil with new nutrients– as a main mechanism for restoring soil fertility. Also, the unavailability of part of the phosphorus and potassium makes it impossible to assign an economic value to the depleted elements.

Another approach counts only soluble, directly available nutrients. These however fluctuate considerably during yearly cycles that involve mineralization (breakdown into mineral constituents) of organic matter just after the start of the rainy season and immobilization of nutrients in organic matter at the end of the season. This cycle is very important for yearly crop growth, but does not provide a good description of long-term developments in soil fertility.

The approach advocated here is intermediate between these two approaches. Nutrients are considered to be mineral elements available for plant growth in a period of time that is relevant for sustainability studies, around 15-30 years. In this approach, used by Van der Pol (1991) and based on work of Pieri (1989) and Frissel (1978), the mineral elements in the soil are looked upon as being present in one of three pools: A – elements available to plants (in a period of about 30 years); B – elements present in soil organic matter; C – mineral reserves in the soil. Figure 4 shows the flow of elements in and out of the system and between the pools.

Elements in pool A and elements present in organic matter (pool B) are considered as nutrients. Elements in pool C, the mineral reserve, are not counted as nutrients. Elements from pool C that become available due to e.g. weathering are treated simply as inflows. They

FIGURE 4
Nutrient flows in and out of the system



Source: Frissel, 1978; Pieri, 1989.

are assumed to become available at a constant rate, due to weathering and dissolution of soil minerals.

Strong fixation mainly of phosphorus and potassium is the opposite process, which may occur in certain soils, and is treated as an outflow where relevant.

SOURCES OF NUTRIENTS

Soil, mineral fertilizers, organic matter and atmospheric nitrogen fixed by microorganisms or carried down in precipitation, are the major sources of plant nutrients. The natural plant nutrients found in the soil are deposited there from the air or from water, or made available through nitrogen fixation or through weathering of soil mineral particles. Vegetation takes up some of these nutrients, some are redistributed in the landscape by runoff, and some are lost by volatilization, fixation and leaching. Farmers harvest the natural supply of these nutrients in their crops and reorganize their distribution in space and time through their production systems.

Soils contain natural reserves of plant nutrients in quantities that depend on soil composition and stage of weathering. These reserves are often in forms unavailable to plants, and only a minor portion is released each year through biological activity or chemical processes. Nutrients such as NH_4^+, K^+, Ca^{++}, Mg^{++}, etc. are held on the clay particles in an exchangeable form, available for use by the plants. Soil organic matter serves as the principal storehouse for supply of anions such as $H_2PO_4^-$ or $S0_4^{2-}$ to the plants. These anions are made available to growing plants in the soil solution through the decomposition of soil organic matter by various micro-organisms present in the soil.

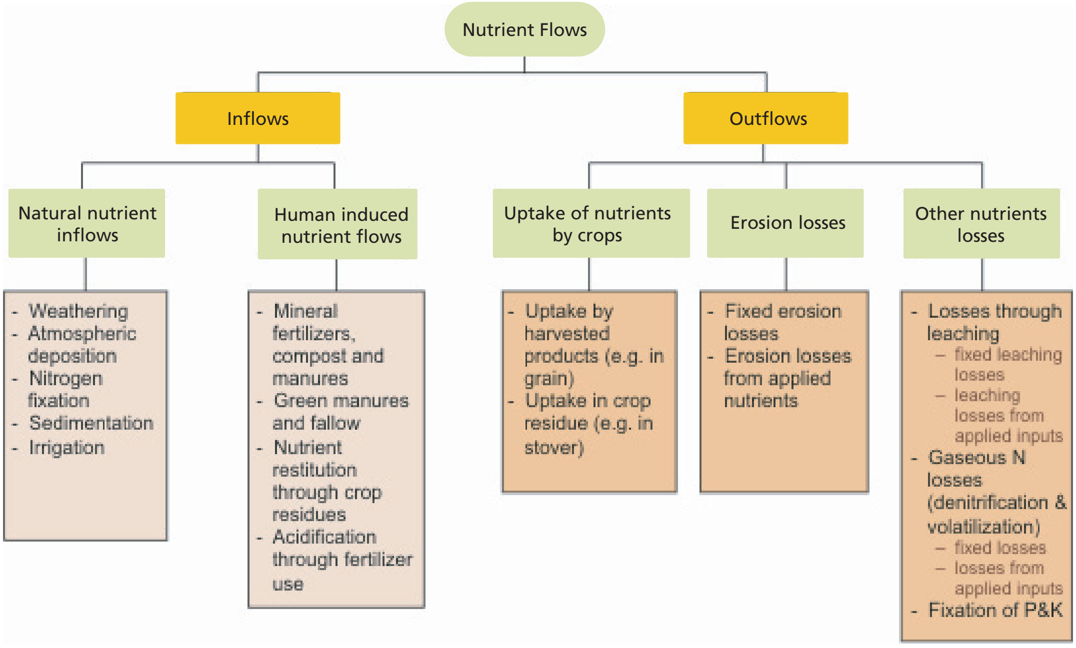
The quantities (or stocks) of plant nutrients available for a crop are determined by the nutrient inflows from internal and external sources, and the nutrient outflows to the environment. Thus plant nutrient stocks are constantly changing. To enhance the nutrient supply it is necessary to reduce nutrient outflows to the environment through adoption of suitable soil-crop-input management practices.

Mineral fertilizers can provide nutrients to the crops in readily available form and in required quantities. Soils with poor nutrient reserves may be transformed into highly productive systems with adequate fertilization and proper management. Fertilizers are an important tool for maintenance of soil productivity.

Organic manures are valuable by-products of farming and allied industries, derived from plant and animal sources. The available organic resources include farmyard manure and animal droppings, crop wastes and residues, sewage sludge and other human wastes and various industrial wastes. Improvements in use of organic nutrient sources can be sought through enhanced and improved organic recycling (Misra & Roy 2003). Use of organic manures as a nutrient inflow resource not only supplements the nutrient availability but also improves the biophysical properties of the soil and enhances mineral fertilizer use efficiency.

Legumes contribute to soil fertility through their ability to fix atmospheric nitrogen in association with Rhizobia. There are good prospects to enhance nutrient inflows through exploitation of symbiotic and non-symbiotic biological nutrient resources: Rhizobium-legume symbiosis and other associations such as Cyanobacteria (blue-green algae), Azolla, Azotobacter and Azospirillum. Agroforestry systems also contribute to soil fertility improvements through beneficial associations between various species constituting the systems.

FIGURE 5
Flows affecting the nutrient pool



Source: Based on Moukoko and van der Pol, 1999.

QUANTIFICATION OF NUTRIENT FLOWS

Flows affecting the nutrient pool (Figure 5) are classified in the following categories, discussed below in some more detail: natural nutrient inflows; human-made nutrient inflows; uptake of nutrients by crops; erosion losses; losses by leaching, volatilization and denitrification.

Natural nutrient inflows

Especially in low-input agricultural systems, the contribution of natural processes is significant. It was estimated for southern Mali that 56 percent of the total N import, 43 percent of the total P import and 53 percent of the total K import became available through natural processes (Van der Pol 1992). Thus, natural input processes in this region were just as important as the combined input of organic and mineral fertilization. In the present approach the following five processes are accounted for.

Weathering, the alteration and dissolution of soil minerals, is considered to be the source of a constant inflow of nutrients, each year adding the same quantity of nutrients to the stock.

Atmospheric deposition in rain and dust brings in nitrogen, phosphorus, potassium and other elements. Not the total quantity of elements deposited in dust are nutrients; a fraction (e.g. of potassium) is present in non-available forms.

Non-symbiotic nitrogen fixation and enrichment through trees left in the field is a natural inflow that is assumed to be constant each year. Symbiotic N fixation by leguminous crops is assumed to supply a certain proportion of the total N requirements of these crops, and is calculated separately.

Sedimentation of silt and clay in valley bottoms or in plains during flooding by larger rivers also brings in nutrients, but their precise amount is difficult to estimate. In Bangladesh estimations have been made based on the thickness of the sediment layer deposited and its nutrient content. In most cases the quantity is high enough to prevent fertility problems. Only under intensive cropping without or with unbalanced fertilizer or manure application fertility problems are expected. Quantification of this type of inflow is important to estimate the effects of dams and flood control measures on agricultural productivity downstream.

Irrigation water may be supplying significant amounts of dissolved nutrients to crops. Quantification is based on nutrient contents in irrigation water and water use per crop.

It is more important to obtain an estimate of the total natural inflow than to assess the individual flows. Data on weathering and atmospheric deposition are rarely presented directly, but can sometimes be estimated indirectly. For example, for West Africa unique and detailed studies by Nye & Greenland (1964) on the regeneration of natural vegetation and on nutrient accumulation during the regeneration period provide insight into the total natural inflow.

Human-induced nutrient inflows

Four types of human-induced inflows are taken into account.

Mineral fertilizer, compost and manure applications are considered as practices providing nutrients to the crops on which they are applied. The corresponding nutrient inflows are calculated on the basis of the quantities applied.

Green manure and fallow are considered as separate crops generally with a positive nutrient balance. The balance is calculated on the basis of crop data and yields. Corral systems, in which animals are confined during a fallow period on a field, are also considered as a fallow crop with inputs related to the number of animals and the duration of the corral period.

Nutrient restitution through residues left behind in the fields is considered as diminishing the uptake of the crop that provided the residues (and not as an input for the subsequent crop). However, harvested residues, returned often in a mix with farmyard manure, are treated as inputs for the crops to which they are applied.

Acidification of soils by urea and ammonium fertilizer (often quantified as the lime requirement of these products), treated as a negative lime flow which should be compensated by applying other materials with a positive lime flow (organic matter, lime).

Nutrient uptake by crops

In most known cases nutrient uptake by crops represents more than 50 percent of the total outflows. The associated nutrient flows are estimated as a function of crop yields and nutrient uptake data per tonne of crop yield. To allow calculation of nutrient flows under various residue management practices, uptake by crops is split into uptake by harvested products (e.g. in grains) and uptake in residues (e.g. in stover). Uptake is calculated from yield and nutrient contents in harvested products and residues.

Nutrient losses

Four types of nutrient losses are considered.

Losses by erosion can be substantial. They are estimated on the basis of the quantities of sediment lost and the nutrient content of the sediment. The sediment also contains elements incorporated in clay minerals and therefore not available as a plant nutrient. A fraction of the total element content of eroded material is defined as nutrient.

Inter-annual weather fluctuations are found to cause considerable variation in erosion. On a time scale of 15-30 years, however, these variations will average out.

Erosion losses can be split into fixed erosion losses, that occur without any application of fertilizer and manure, and erosion losses from applied inputs, expressed as a percentage of what has been applied. This approach allows estimation of nutrient balances under various fertilization regimes.

Losses through leaching are split into fixed leaching losses and leaching losses from applied inputs, as done for erosion. Leaching losses can be substantial for nitrogen and potassium, but not for phosphorus. Leaching is reportedly an important cause of decline in the organic matter content of soils after clearing for cultivation (Nye & Greenland 1960). Soluble plant nutrients lost to deeper soil layers cannot be incorporated in the organic carbon cycle of the topsoil. Leaching losses will depend on the types of crops grown, fertilization, rainfall, soil texture and infiltration rate. The calculation procedure presented has provisions to take these influences into account.

Gaseous N losses caused by denitrification and volatilization are most frequently reported in connection with fertilizer use. But gaseous losses through mineralization of soil organic matter should not be ignored. Therefore also gaseous losses are split in fixed losses and losses from applied inputs.

Fixation of phosphorus or potassium, occurring in certain soil types, could be regarded as a nutrient outflow. Fixation is most frequently reported in connection with short-term fertilizer use. Birch found that within 10 years nearly all of the phosphorus fixed by a Hawaiian soil was released again and taken up by subsequent crops. In such near-steady-state cases fixed elements can be regarded as nutrients and fixation need not be considered a nutrient outflow.

In a study of Kisii district in Kenya, the two largest outflows were harvested product (a positive outflow-from the point of view of the farmer) and erosion (a negative outflow). Kisii is a highland district with high rainfall resulting in runoff on sloping clay soils. A management system that is responsive to these factors would comprise inflow management with sufficient fertilizer to support crop growth and outflow management that promotes high yield (harvested product), high levels of residue return and minimal erosion. The optimal combination of inflow and outflow management would result in high profits that were sustained over time (Weight & Kelly 1999).

NUTRIENT FLOWS AS AFFECTED BY FARM MANAGEMENT

Farm management practices affect the nutrient flows to a considerable extent. Management practices vary greatly from one location to another. On-farm crop-soil-water-input-output management involves many aspects with an effect on nutrient flow pathways and their intensity. Crop-soil-water-input management practices such as selection of appropriate crops and varieties, correct time of sowing, proper spacing, use of soil amendments where required, appropriate water management, proper weed, pest and disease control, use of appropriate fertilizer types and application rates, appropriate dosage, right time and method of fertilizer application, and correction of micronutrient deficiencies may boost crop nutrient uptake, resulting thereby in higher useful nutrient outflows through harvested crops and crop residues. Inappropriate crop-soil-water-input management practices may result in substantial outflows through leaching, gaseous losses and run-off and erosion processes.

Water management plays an important role in nutrient flows. Regulated irrigation using just enough water at various stages of crop growth, as recommended for the crop, minimizes nutrient outflow. Excessive irrigation leads to nutrient outflows through leaching, particularly of N and K. Under waterlogged conditions there may be appreciable nutrient outflows through gaseous pathways. Excessive water in the soil at the time of fertilizer application and immediately thereafter tends to increase nutrient outflows.

Management practices related to crop sequencing and introduction of leguminous crops in rotations and intercropping systems as well as use of bacterial or algal cultures can increase nutrient inflows since legumes and cyanobacteria (blue-green algae) can fix atmospheric nitrogen.

The management of farm outputs such as crop residues also affects the nutrient flows. For example, there are various options to deal with the crop residues: stocking them for livestock feed or litter; composting them directly with other organic wastes; or burning them in the fields.

Residues left in the fields and not burnt could be grazed in situ by livestock, and the remainder allowed to decompose. One could make a distinction between grazing by the household's own animals and by animals from other farms. Grazing by one's own animals is, like stocking or composting, a transfer that potentially keeps nutrients within the same field-herd-household, while grazing by other animals exports nutrients outside of that system (Ramisch 1999). Since manure, mostly produced by the own herd, is included as an inflow in the nutrient budget, it is not necessary to make a distinction in the calculation of the outflow through grazing.

Management-related transfers involving all the intentional movements of organic matter to the fields from livestock pens or compost pits, as well as the application of inorganic fertilizers have an impact on nutrient inflow. The manure from livestock corralled on fields in the dry season is also a management-related input. Management also influences the movement of livestock within and across the fields, determining the nutrients introduced in passing by grazing animals allowed to use the field as corridors across the landscape even after the residues have been consumed (Ramisch 1999).

SCALE ASPECTS AND DEFINITION OF TARGET AREAS

Scale aspects are important in studying nutrient flows (Fresco and Kroonenberg, 1992). Nutrients are generally not disappearing (except when elements are transformed in forms unavailable to plant growth, e.g. through denitrification, and thus are no longer regarded as nutrients). In most cases, however, nutrient flows are redistribution processes. If a field or a region presents a net outflow of nutrients, the question is where those nutrients can be traced after e.g. two years. Where are nutrients lost by erosion deposited? Where could nutrients exported in grain be found afterwards?

Consideration should be given to these redistribution processes when defining target areas. In one area one might find parts with nutrient accumulation, and other parts with depletion. Four processes of redistribution are very common:

- Nutrients are depleted from remote fields and pastures and concentrated around villages through systematic use of manure and residues on garden fields, which can be better guarded and where access is easier.
- Nutrients are concentrated around cities on plots used for intensive vegetable and fruit production, generally based on use of city waste.
- Nutrients are accumulated in floodplains through deposition of silt and clay eroded upstream.
- In arid zones cultivation is often only possible in valley bottoms receiving both water and nutrients from larger non-farmed areas upstream.

The present methodology is developed to describe nutrient depletion and erosion as a result of agricultural production and to attach a value to the environmental cost associated with it. It is not recommended to mix in this description areas with nutrient deficits and with surpluses to describe non-existent average situations. As long as those areas have separate cropping systems, they are better analysed separately. This is quite different from the situation in crop rotations, where demanding crops can be alternated with fertility-restoring crops or fallow on the same fields In such cases a description can be given of the development of such a system in the long term.

The above-mentioned aspects should be kept in mind when defining target areas. In fact the calculation method presented can be applied at any scale –field, farm household, region or nation– as long as separate and different systems of land use are not mixed.

DATA REQUIREMENTS

In most cases, data have to be collected from two different sources. Data concerning the physical processes of nutrient flows and erosion losses are probably best obtained at scientific institutions or through literature research. Data describing the farm and the farmers' practices should be obtained at farm level or from statistical data providers. Data requirements from these two sources are indicated below.

General data to be collected from literature or at research institutes are:

Generally available data

- Nutrient content per kg harvested product for each crop
- Nutrient content of residues per kg harvested product for each crop
- Nutrient content of manure and compost
- Nutrient content of excreta of cattle used in a corral system

Data requiring results from specific studies

- Rate of erosion under different crops on major soil types, eventually as a function of annual rainfall
- Nutrient content of eroded material
- Leaching losses under crops on major soil types
- N losses by denitrification or volatilization under different crops on major soil types
- Percent losses from inputs by erosion, leaching and denitrification or volatilization under different crops on major soil types
- Other effects of erosion (on soil depth and structure)
- N nutrient inputs by natural processes such as weathering, atmospheric deposition, N-fixation and flooding (or to be estimated from regeneration of natural vegetation in the target area).

Data to be collected from surveys are:

General surveys

- Area under each crop
- Yield of each crop
- Fertilizer and lime applications

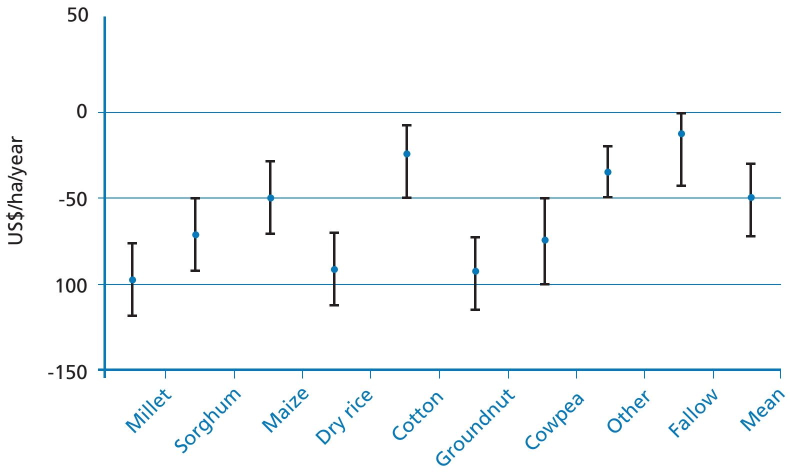
Specific surveys

- Area under fallow
- Manure practices
- Grazing practices
- Residue restitution practices
- Major adaptations of cropping systems to soil types

RELIABILITY AND CONVERSION OF DATA

The implementation of the methodology requires a large variety of natural resource, environmental and socio-economic data. These data are usually dispersed over various agencies, government departments and institutions. The data concerning the physical processes of nutrient flows and erosion losses obtained from scientific institutions or through literature search are quite reliable, but not always precise, as they could present variations from case to case. As far as possible they should be based on studies pertaining to the relevant area.

FIGURE 6
Reliability intervals of nutrient deficit market values



Source: Based on data by Van der Pol, 1991.

The precision of outcomes cannot be better than the precision of basic data. Losses by erosion, inflows by natural processes and nutrient contents of crops are usually not known very precisely. For the potassium balance residue restitution is an important contributor to uncertainty.

Typical margins between optimistic and pessimistic estimates are around 25 kg/ha per year for N and K, and around 4 kg/ha per year for P. In monetary terms, typical margins are around US$ 40 per ha (Figure 6).

Due care should be taken during collection of data describing the farms and the farmers' practices to ensure reliability. Data such as crop yields, nutrient inputs, and residue management, as provided by farmers directly, could be checked through follow-up questions and observations in the field. Units should be standardized, involving conversions such as volumes to weights, and wet weights to dry weights, and these conversions should be checked carefully.

To fulfil accurately the data requirements of the methodology, it is advisable to operate with an interdisciplinary team. Many data from literature reviews and in-situ studies require considerable analysis and interpretation. In order to manage data coming from different disciplines, it is advisable to combine the expertise of soil scientists and socio-economists, together with extension agents.

Once this information has been analysed, the data entry does not require strong computer knowledge and capabilities. The methodology uses a workbook spreadsheet in Excel designed following the principles discussed above. Specifications on how to enter the information are contained in the operational manual.

Long-term measures to overcome the problems of reliability and conversion of data include capacity building –including training– and institution building aimed at creating an environment and framework conducive to the development of integrated natural resource and economic accounting at defined operational levels.

4. Valuing soil mining, erosion and soil recovery

VALUATION OF ENVIRONMENTAL ASSETS

Environmental change often is not easy to evaluate because of various reasons, such as obvious difficulties of valuation, choosing a proper technique and concept for valuation, which will depend on what is being measured, scope of the analysis, physical and social externalities, time preferences and discounting, time horizon, risk analysis and uncertainty effects. Some of these aspects are discussed below.

Risk and uncertainty

Questions of risk and uncertainty play an important role in environmental valuation and policy formulation. When probabilities can be assigned to the likelihood of an undesirable event, we speak of a risk. Uncertainty describes a situation where so little is known about future impacts that no probabilities can be assigned to particular outcomes; or outcomes may be so novel that they cannot be defined. Generally two types of uncertainty are distinguished with regard to environmental assets (Pearce & Warford, 1993): supply uncertainty, concerning the continuing availability of the environmental asset in question; and demand uncertainty, relating to uncertainty about whether in fact a commodity will be in demand at a time in the future.

The usual response to uncertainty and risk is to proceed with caution. If the future cannot be perceived clearly, then the speed of advance must be reduced (Munasinghe & Lutz, 1993). In other words, the scope and pace of change should be limited to the extent to which outcomes can be anticipated or the possibility of retracing one's steps can be maintained.

Time preferences

Another long-standing problem in project evaluation is how to compare present and future costs and benefits. It is widely accepted that costs incurred and benefits secured in the present should have more weight than those expected to arise in the future, and that the latter should therefore be discounted to their equivalent present value. In practice this often leads to a situation in which future benefits of environmental assets are discounted to such a degree that they do not balance the cost of preservation now. Also, individual decisions may differ from social decisions: individuals are relatively short-lived and risk-prone, whereas societies persist for much longer and can spread risk, and therefore have less reason to discount the future.

It is sometimes argued that the marginal productivity of capital will be higher in developing countries, reflecting slack capacity and the relative scarcity of investment capital. The rate of consumer time preferences may also be elevated in many cases, at least among the very poor, who must give priority to satisfying immediate basic needs rather than to ensuring long-term livelihood security. It is further argued that the resulting higher discount rates will discriminate against future generations, to the extent that costs arising in the long term will be discounted (if taken into consideration at all), while net benefits occurring in the near term will have greater weight. Similarly, under high discount rates projects with benefits that accrue in the long term are less likely to be undertaken.

Valuation concepts

A number of concepts have been used in valuing natural resources. For any pollution-causing commodity, Noman (1996) invokes the concept of marginal social costs. These costs reflect the fact that prices of goods and services associated with pollution (during production or consumption) are likely to be too low and should include marginal pollution damage in monetary terms.

Marginal opportunity costs (MOC) are used to conceptualize and measure the physical effects of resource depletion in economic terms (Schramm & Warford, 1989). MOC refer to the costs borne by society and include direct costs to users associated with the depletion of the resource; costs imposed on others, either now or in the future; and net benefits foregone by those who might have used the resource in the future.

Different uses and services of the environment are captured in the concept of Total Economic Value. This concept facilitates the understanding of the origins of different values. The total economic valuation framework therefore is primarily a means of identifying different uses and services that could be potentially provided by an environmental good or service (Dharmaratne & Strand, 1999). The total economic value expresses in monetary terms the broad types of benefits that accrue from natural resources. It involves valuation of specific environmental assets, and includes five types, briefly described below.

Direct use value – The environment provides many goods and services, which could be directly consumed or used in the production process of consumable goods. The capacity of a resource, when used, to satisfy a particular preference, e.g. of hunters, tourists or slash-and-burn farmers is expressed through this value.

Indirect use value – The environment provides valuable services and functions that indirectly assist in the consumption and production process or prevent destruction of consumable goods or productive assets. This value reflects the ecologists' concept of environmental functions or services provided by the resource, e.g. the role of forests in providing favourable weather conditions, preventing soil erosion, promoting nitrogen fixation and carbon sequestration; role of wetlands in preventing floods.

Option value or potential use value – The value that society places on potential future use of an environmental asset, i.e. the amount that individuals are willing to pay to conserve an asset for future use. Since there is a risk that the environmental good or service may not be available in the future, users may be willing to pay a risk premium to guarantee availability.

Existence value – People may gain satisfaction from the knowledge that certain environmental goods exist and therefore may be willing to pay for their continued existence. Individuals place this value on environmental assets that they may not use, but whose existence is nevertheless valued, e.g. natural heritage or wildlife.

Bequest value – The willingness to pay for conservation and preservation of the environment, to avoid irreversible changes specifically for the benefit of future generations is known as the bequest value. This value people derive from knowing that others (perhaps their own offspring) will be able to benefit from the resource in the future.

Option values, existence values and bequest values in particular are often treated with caution because of the ambiguities associated with defining these concepts, a well as the possibility of double counting the value of indirect supporting functions and the value of the resulting direct use.

VALUATION METHODS

A wide ranges of valuation techniques is available to measure value to users of environmental goods or services. Depending on the type of use, either market based methods; surrogate or implicit markets or survey-based techniques could be used for valuation (Dharmaratne & Strand, 1999). A brief description of generally used methods is given in the following paragraphs.

Market-based methods

Market-based methods use market prices for valuation. These methods are simple and easy in application. Calculations can be done using one of five simple accounting techniques: the replacement cost approach; change in productivity approach; loss of human capital approach; preventive expenditure approach; or the shadow projects approach.

Replacement cost approach

In the replacement cost method, the costs to be actually incurred to replace damaged productive assets are estimated (Dixon and Hufschmidt, 1986). It is assumed that depleted nutrients should be replaced as a means of conserving or restoring the quality or value of the soil to its former condition for future generations. Nutrients are considered to have an economic value equal to the market value of an equivalent amount of fertilizer.

Change in productivity approach

Changes in productivity of resources, environmental goods or services occur because of environmental changes. Cost of environmental change could be estimated using market prices. The difference in the value of production before change and after the change provides a measure of the loss of value due to an environmental change. The application of the method involves a two-step procedure viz. the estimation of the physical effects of nutrient change on crop yield as the first step followed by the estimation of the value of the resulting change in production as the second step.

Loss of human capital approach

The method resembles the approach followed in the change in productivity method, except that it is applied to human capital rather than natural capital. The method is based on the principle that the environmental change, especially pollution-related environmental degradation, will increase morbidity and mortality and thereby affect the quality and quantity of human capital. This loss of human capital is reflected in the loss of productivity resulting from loss of work days and in extreme cases, premature death. Therefore, the total loss would be the value of lost production plus the cost of treatment.

Preventive expenditure approach

To mitigate adverse environmental effects, individuals may spend money on appropriate preventive measures such as groynes to prevent coastal erosion, or inundation control measures to substitute for the role of former swamplands. The method envisages that it becomes necessary to incur expenses to replace or simulate a natural function which was provided earlier by the environment, but presently unavailable because of environmental degradation.

Shadow projects approach

The shadow projects approach takes the replacement cost approach one step further. The method estimates the complete cost of replacing a range of environmental goods and services.

In cases where it is difficult to value individual items in an ecosystem or when most services and functions are unknown, this method has better applicability. The theoretical cost of a project that will replicate or provide close substitutes is estimated through this method. The value of environmental assets as a part of the total opportunity cost of a development project may be well specified through this approach.

Non-market-based methods

Some goods and services, such as free public beaches or parks, recreational fishing or wildlife viewing, are not traded in the market. Consumers do not pay a market price to gain access to them. Nonetheless, individuals benefit from their use and loss of access to these non-market goods may cause significant welfare losses to individuals. A variety of methods have been developed to measure these non-market values (Dharmaratne & Strand 1999): the contingent valuation method (CVM); travel cost models; random utility models (RUM); hedonic methods; and averting behaviour models.

Contingent valuation method (CVM)

One of the ways to measure non-market values is to ask individuals in some form or another the maximum amount that they would be willing to pay to avoid the loss of a public convenience. The contingent valuation technique constructs a realistic but hypothetical market that exists as it is described by the interviewer, and participants respond to a change in environmental quality by stating their maximum willingness to pay to avoid the change. Contingent valuation studies are conducted as face-to-face interviews, telephone interviews or mail surveys.

Travel cost models

This method is applied to measure recreational values. Individuals expend both money and time (which they clearly value) to access a recreational site. These act as surrogates for the price of the goods. A demand curve for trips using the surrogate prices can be estimated from the information and changes in areas used to measure values. The travel cost approach (developed by Clawson 1959 and Clawson & Knetsch 1966) has been extensively used in developed countries to value recreational goods and services (Dixon *et al.,* 1992). The method has been applied in Costa Rica (Tobias & Mendelsohn 1991) to measure the value of eco-tourism at a tropical rainforest site and in Kenya (Brown and Henry 1989) to estimate the demand function for safaris (in Munasinghe & Lutz 1993, p. 42).

Random utility models (RUM)

RUMs are similar in concept to the travel cost models and adopt the same sorts of values and principles. These models focus on the tourists' choice among the discrete alternative recreational sites instead of focusing on the number of trips a tourist takes to a given site. This type of model is particularly appropriate when there are many options available to the individual.

Hedonic methods

Hedonic pricing refers to techniques that isolate the influence of environmental amenities or risks on market prices of properties or on wage differentials. Hedonic pricing has been used in North America to value the effects of soil degradation on agricultural land prices. Hertzler *et al.,* 1985, evaluated the loss of productivity due to soil erosion on farmland in Iowa. The costs of conservation structures were found to be capitalized into land prices only when the need for such investments is obvious (Gardner & Barrows 1985, cited in Bishop, 1995).

Averting behaviour models

In some instances, the minimum expenditure necessary to avoid an environmental nuisance can be a justifiable lower-bound estimate of the economic loss (compensating variation) from environmental degradation. If individuals wear masks to avoid air pollution and this is sufficient for its avoidance, then a lower bound on the individual's willingness to pay for improved air quality would be the expenditures associated with wearing masks. The literature on averting behaviour seems conceptually the same as previous models except that one examines the expenditures directly rather than demands (Dharmaratne & Strand 1999).

VALUING CHANGING SOIL QUALITY: VALUATION METHODS FOR SOIL MINING, EROSION AND SOIL RECOVERY

Two valuation methods, the replacement cost method (RCM) and the change in productivity method (CPM) are generally used to assess in monetary terms the benefits and costs related to changes in the value of the soil. Of all methods, these two have been most commonly applied in the economic evaluation of soil, largely because of difficulties in applying the other methods in such contexts (Grohs 1994; Enters 2000; Bojö 1996; Drechsel *et al.,* 2004).

The replacement cost method (RCM)

The most common methodology for the economic assessment of soil nutrients is the RCM. The method is relatively simple to apply when nutrient loss data are available (Bojö 1996; Predo *et al.,* 1997; Drechsel & Gyiele 1999). The RCM measures the costs that might be incurred to replace damaged or lost soil assets, such as nutrients through erosion, leaching or harvest (Grohs 1994). It could also be used to value nutrients gained (Drechsel *et al.,* 2004). The method assigns monetary values to depleted soil nutrients by calculating the cost of purchasing an amount of mineral fertilizer with a nutrient content equivalent to the amount lost.

Market prices are usually available for common nutrients; making assessments simple once the nutrient database is obtained. However, caution must be used in applying input prices, as the appropriate price to be applied depends on the purpose of the analysis. Local market prices might be appropriate to determine financial implications for farmers, while a world market price might be used to calculate societal impact at the national or international level (Drechsel *et al.,* 2004).

There are some basic limitations with the RCM approach. For example, on the one hand, not all fertilizer applied is used by plants (a certain amount will be lost), thus the quantity needed for full replacement will be higher than that suggested in RCM calculations. Further the soil nutrients may not be the (only) limiting factor in production, and so their loss may have no real economic value or a value less than the full replacement costs in the actual production system. If total element balances would be used (which is not advocated in the present methodology), a significant portion of lost nutrients might not have been plant-available, and so there is no justification for putting a cost on their replacement (Drechsel *et al.,* 2004). RCM as normally applied only places value on nutrients that can be easily replaced. It does not, for example, consider the cost of replacing damage to soil structure that might also accompany nutrient loss and which would not be addressed through fertilizer application (Enters 1998). Thus, the RCM does not assess all the costs of avoiding damage to soil fertility. Rather, it assesses the costs that will be incurred if a damaged asset is restored. Notwithstanding these limitations, the ease of use of the procedure and the possibility of incorporating necessary adjustments make the technique a potentially valuable methodology.

Some cases in which this method has been used are summarized below.

On-site and downstream costs of soil erosion in the Philippines were evaluated on the basis of lost nutrients. Off-site costs were estimated based on the shorter reservoir and dam service life; the opportunity cost of providing excess sediment storage capacity; and a reduction in useful storage capacity of the reservoir (Cruz *et al.,* 1988).

In Zimbabwe, Stocking (1986, cited in Bishop 1995, p.19) estimated losses of three major plant nutrients using soil erosion data for farmland. Nutrient losses were valued as the cost of applying equivalent quantities of mineral fertilizer.

In Southern Mali, nutrient losses due to crop uptake, erosion and volatilization for the main cropping systems were expressed in terms of equivalent quantities of mineral fertilizer, and valued using prevailing market prices (Van der Pol 1992 and Van der Pol *et al.,* 1994).

In sub-Saharan Africa, IBSRAM conducted a continental-scale assessment of the costs of soil nutrient depletion (Drechsel *et al.,* 2001). The research goal was to inform policymakers of the hidden costs of soil nutrient mining so as to highlight the potential impact and benefit of soil conservation investments. RCM was employed using nutrient balance predictions (N, P, and K deficits).

In Ghana, in West Africa's tuber belt, IWMI used the RCM to analyse the costs of soil nutrient depletion in two farming systems along an urban–rural gradient in and around Kumasi (IWMI 2002).

In Colombia, the National Corporation for Agriculture Research (CORPOICA) assessed the sustainability of small scale farmers' income using the methodology of integrating environmental and economic accounts (IEEA), with the technical assistance of FAO. The RCM was used to establish accounts that reflect real sustainable income at the farm level and measure the financial contribution of land resource assets (Santacoloma *et al.,* 2005).

In Costa Rica, in a collaborative effort the Department of Central Agricultural Conservation, the Research Department, and the Bureau for the Central-Eastern Region, with technical assistance by FAO, conducted a study on implementation of IEEA. The RCM methodology was used to assess the sustainability of small scale farmers' income (Santacoloma *et al.,* 2005).

The change-in-productivity method (CPM)

The change-in-productivity method is based on an estimate of the value of future (potential) loss of production due to nutrient depletion if the replacement of such nutrients is not carried out. The work of Bishop & Allen (1989) provides an example. They estimated the effect of soil loss on crops under permanent cultivation in southern Mali. The yield declined from an initial value of 1500 kg/ha to 400-800 kg/ha during ten years of continuous cultivation (by 2 to 8 percent per year).

The Change in Productivity Method (CPM) has been widely used to assess the economic costs of natural resource degradation. The method has a logical, straightforward approach for application and is easy to follow. CPM can be used to measure actual change or, when coupled with yield simulations, to assess likely impacts of possible interventions. However, most of the studies have used the CPM for assessing the effects of soil erosion by water. They have not covered other nutrient-depletion processes, largely because the method becomes difficult to apply when specific factors such as soil nutrient change are of interest rather than overall changes in land services affecting crop productivity (Enters 1998).

The CPM does not focus on the actual costs of nutrients as in the case of RCM. Rather, it places a value on the services soils provide in terms of crop yields. The CPM assumes that the value of productivity change is equal to the difference in crop yields with and without that change, multiplied by the unit price of the crop, which is, or might be grown, potentially adjusted to reflect any differences in the costs of production (Barbier 1998).

A fundamental limitation of the CPM is its dependence on the actual production system. Where the prices of agricultural products are low and prices of nutrients are high in a production system, CPM will describe what is feasible for farmers –in such cases most probably to deplete their soils–, but will not describe the loss in natural capital.

Some cases where this method has been applied are summarized below.

In the northern Thai uplands (Dixon *et al.,* 1992), evaluated three main land-use alternatives: exploitative mono-cropping, with continuing erosion and degradation as a consequence; construction of physical structures aimed only at minimizing erosion; and control of erosion and degradation through conservation-oriented farming practices, either alone or in combination with physical structures. The study presents a comprehensive analysis of both on-site and off-site effects.

In semi-arid Kenya, costs of various practices (land, labour, farm inputs, and construction of physical structures for soil and water conservation) were compared with benefits observed in maize (grain yield and biomass production). Short-term net benefits and longer-term net present values were calculated for the various conservation measures (Kiome & Stocking 1993).

Costs and benefits of stone bunds in Burkina Faso have been calculated by De Graaff (1993 and 1996). Differences in yields on fields with and without bunds were compared with the costs of establishing the stone bunds. Yield losses were estimated using a production function that relates yield to nitrogen loss caused by erosion.

In Ethiopia, Bojö & Cassells (1995) have explored economic losses as a result of soil erosion.

Erosion costs in Indonesian uplands have been measured on the basis of declines in physical crop production (assessed per one per cent change in land degradation) and the related decreases in crop productivity.

On-site costs of soil erosion in Mali were estimated by Bishop (1995) in a study of the effects of soil degradation (erosion) on both traditional subsistence farming and export agriculture. This study displays the typical problems of productivity approaches: the links between productivity decrease and degradation are weak. In this case long-term productivity decrease was assumed to be due to erosion; rainfall and fertility decline were not considered.

Replacement cost method vs. change in productivity method

While the RCM attempts to place a value on actual nutrient loss or gain, the CPM attempts to value the change in production caused by that change. Further, the replacement cost method provides a true cost of replacement of nutrients if depletion has actually occurred, but it does not measure the benefits of undertaking the repair of the damage caused to the soil. This is done by the change in productivity method, on the basis of actual production systems. While the CPM has certain advantages, it also suffers from a number of inherent problems such as the difficulty in linking yield with nutrient loss (Nye & Greenland, 1960; Lindgren, 1988; Theng, 1991; Prasad & Goswami, 1992; Enters, 1992). Also, the analysis must distinguish and isolate technological progress and changes in farming practices, and their effects on yields, from nutrient change.

None of the two methods allows for estimation of the off-site cost and benefits of soil mining and erosion, such as the cost of siltation of hydropower lakes, flooding, negative impact on productivity of soils downstream, negative consequences of erosion for downstream irrigation and water supply, pollution by nutrients, the socio-economic cost of people leaving their degraded soils for settlement in other regions, or the benefits from the formation of fertile soil in valley bottoms and floodplains and the maintenance of fertility in areas around settlements through nutrient transfers from mined soils.

For analyses of nutrients specifically, as opposed to broader soil services, the RCM has an obvious advantage in that it is tied directly to the nutrients themselves. When the focus is on soil fertility change or soil degradation (or improvement) in general –for example through erosion which not only affects nutrients but soil broader soil services–, the CPM becomes increasingly attractive as it implicitly considers all biological, chemical and physical soil properties affecting soil productivity. On the other hand, many farmers facing soil nutrient depletion and erosion problems are in a transition type of agriculture as described in Chapter 2, where shorter fallow periods force a transition to more efficient new cropping practices. They generally face low prices for products and high prices for inputs. The use of current production systems and prices for assessing the value of natural assets is then limited. Because of this dependence on current production systems RCMs are preferred over CPMs in environmental studies.

Another consideration in choosing between the two approaches is data requirements and availability. The RCM has the clear advantage that it is simple to apply once net nutrient losses or gains are known since market prices for key nutrients are usually available (Drechsel *et al.*, 2004).

Systematic use of the replacement cost method is suggested as a basic approach in the present study. The main premise for this choice is that soil is assumed to be a productive asset that must be conserved for future generations. In many developing countries, the contribution of the stock of natural nutrients to agricultural production entails consumption of natural capital and a declining productive capacity of the soil. This implies the need for a premium on a technique having recourse to sustainability criteria. A systematic use of the replacement cost method is also in line with most development scenarios, which aim for stable or higher yields per hectare. History demonstrates that higher yields cannot be obtained without increasing or at least maintaining soil fertility. This implies that depleted nutrients should ultimately be replaced.

VALUING NUTRIENTS ON THE BASIS OF FERTILIZER PRICES

For the reasons outlined above, this study uses mineral fertilizer prices (cost of replacement) to assign values to nutrients that have been depleted. Acidification is assigned a value on the basis of the cost of the lime required to compensate for it.

It is necessary to decide whether farm-gate fertilizer prices as actually paid by producers –including taxes or subsidies– will be used, or shadow prices, correcting for market distortions. When shadow prices are used, the outcome represents the economic costs of soil depletion from the national point of view. Outcomes obtained by using actual farm-gate prices represent the financial costs of depletion from the farmers' point of view.

Two basic questions remain to be answered that relate to the actual physical process of replacing depleted nutrients by fertilizer. Could depleted nutrients be instantly available for the next crop or should their value be discounted? And can depleted nutrients be replaced by fertilizer nutrients at 100 percent efficiency, and which cost will be involved in the replacement activity?

With respect to the first question, in the present approach, no discount rate is applied. While it is clear that not all nutrients depleted would come immediately available to crop growth, the fertilizer used to replace nutrients would not make available all nutrients instantly and completely to plant growth. Thus it is assumed that the proxy used for nutrient valuation (fertilizer) has the same efficiency as the depleted nutrients.

With respect to the second question, the value of depleted nutrients is based on a purely hypothetical replacement action with 100 percent efficiency: as if every molecule lost is replaced by a molecule from a bag with fertilizer, and this without taking into account any cost associated with the replacement itself nor any losses that could occur from this action. This is a useful simplification: the proposed analysis provides a minimum value that can be compared with the cost of different measures actually restoring soil degradation. These would include not only increased fertilizer application, but also other ways to improve negative nutrient balances such as reducing losses by erosion control, adapting cropping patterns, integrating agriculture and livestock production.

VALUING ORGANIC MATTER ON THE BASIS OF ITS NUTRIENT CONTENT

In the present approach organic matter is valued on the basis of its nutrient content; no separate value is given to the organic carbon present in organic matter, although this would be technically feasible.

The approach is thus based on the assumption that the organic carbon content of the soil establishes equilibrium with nutrients: by net mineralization in the case of soil mining, and by increased root growth and litter production in the case of enrichment. The equilibrium is assumed to be established within a time horizon of about 15–30 years and to involve no additional costs. Hence, organic carbon replacement is considered to occur at zero cost.

There has been discussion on the necessity of applying organic manure or incorporating crop residues into the soil. Matlon & Spencer (1984) stress that incorporation of large quantities of organic material is necessary to maintain and improve the soil's organic matter content. On the other hand, there is evidence that incorporating new organic material burns the more stable humic fraction of the organic matter in the soil, finally producing a soil with less organic matter. However, experience in different countries with zero tillage and maintaining a residue cover on the soil without incorporation has proved effective for increasing soil organic matter contents.

Pieri (1989) emphasizes the importance of organic matter for the efficiency of fertilizer use, but also indicates the positive effects of mineral fertilizers on the organic matter content of soils. In many circumstances adequate mineral fertilization and proper rotations will allow sustained intensification of agricultural production, as has been shown in well-managed long-term fertilizer trials with cotton (Pieri 1989; Henao *et al.,* 1992).

Where the organic carbon content of the soil is not maintained even under sufficient fertilizer application, as shown in the case study in Bangladesh, a specific value for the lost carbon should be included. The quantity of lost carbon is easily derived from the nitrogen deficit, as the carbon and nitrogen cycles are closely linked. In principle the price could be derived from the actual cost of organic manure.

VALUING SOIL EROSION ON THE BASIS OF NUTRIENT LOSS

Soil erosion is valued on the basis of the value of nutrient loss associated with the erosion process. Most literature on the economics of soil degradation is limited to the costs and benefits of erosion control measures (Stocking 1986; Stocking and Abel, 1989). The starting point is that the major cause of degradation is erosion, which can be minimized by soil conservation. Production losses through depletion and other adverse changes in soil fertility are thus all attributed to erosion. Stocking (1986) valued erosion by considering the nutrients lost. His method fits in well with the nutrient depletion approach.

A positive correction might be needed, however, for deep homogeneous, very fertile soils. In such cases, mainly occurring on steep young volcanic ash soils, continuous farming appears to be possible even when there are relatively high soil losses.

VALUING SOIL RECOVERY ON THE BASIS OF NUTRIENT GAINS

Natural processes play an important role in nutrient gain and loss mechanisms in lands used for agriculture. While the production systems suffer nutrient losses through processes such as leaching and erosion, there could be nutrient enrichment through mineral weathering, depositions brought in from elsewhere by wind and rain and, in the case of N, directly from the air through nitrogen fixing organisms. Evidence suggests that the fertility on abandoned fields recovers if the fallow period is of sufficient length.

In a study in Guanajuato, Mexico, valuation of soil nutrient enrichment or gains through the use of wastewater was the main focus (Scott *et al.*, 2000). Wastewater is usually considered as a negative externality, but it can also have positive aspects if its nutrients, when applied through irrigation, reduce the need to apply inorganic or other fertilizers. The RCM was used in the study. The Mexican study calculated the benefits of additional nutrient supply. In carrying out the analysis, the amounts of N and P delivered to fields through untreated wastewater irrigation under current practices were estimated and compared with a scenario using less nutrient-rich treated wastewater.

SCOPE OF THE METHOD

The method presented here has been designed for use in conditions where soil nutrient mining is a key issue as described in Chapter 2. Application of the method under nutrient surplus conditions is possible and may provide useful information on the fate of nutrients under farming systems. However, special precautions are required in the interpretation of the economic results. In those conditions valuation through fertilizer prices is not effective. As the effects are mainly external, they should be treated as a reduction in pollution, and included as such in integrated accounting systems that take pollution costs into account.

5. Integrating accounting systems

In the preceding chapters, physical nutrient flows and their values related to soil mining and erosion have been discussed. How the resulting changes in the quality of land can actually be integrated in current accounting is the subject of the present chapter.

The framework proposed here is consistent with the challenges expressed in the Handbook of the United Nations System of Integrated Environmental and Economic Accounting (SEEA, United Nations, 2000) that provides a macroeconomic-oriented framework for integrating environmental and economic accounting at national level. The handbook recognizes the need for additional efforts to achieve improvements and further advances in specific fields of natural resource and environmental accounting. Most relevantly for the present study, it stresses the need to "define at a more operational level of occurrence of the environmental problems relevant to maintain vital natural resources", and to "develop indicators of qualitative and quantitative characteristics of non-produced natural assets".

The framework is intended primarily to provide methods of accounting for soil nutrient inflows and outflows, particularly those caused by soil mining and erosion but also by other natural and human-induced processes. The aim is to present existing data –or data that can be generated– in summary and meaningful formats that will enable the integration of environmental and natural resource use considerations into economic policy and decision making. Because the emphasis is on on-site, operational sustainability regarding soil fertility management, the main data sources for the proposed system are crop models, representative farm models, farming systems types, farm household models and ecological area models. However, by accounting for changes in the quality of the soil, the system may also provide a direct contribution to the development of the SEEA, particularly with respect to land and soil accounts.

The review of the concepts and principles underlying the conventional farm accounting system and the evolving nutrient accounting systems shows the need and opportunities for some kind of integration. It has become apparent that such integration can be achieved by introducing limited adjustments to the existing accounting structure.

Environmental and economic accounting can be integrated in two phases, which can be used in sequence; however, the completed first phase already provides useful results.

The first phase is integration by addition of satellite accounts: adding nutrient asset flow accounts as satellite accounts to conventional economic accounts. The newly established nutrient flow accounts are shown side-by-side with the conventional economic accounts as separate account entities, to be referred to as satellite accounts. The SEEA uses the term juxtaposition, implying that satellite accounts are established as a first and necessary step in the integration process. They provide for cross-account analysis between the two categories of accounts and, as a result, for integration of economic, environmental and natural resource use analysis and their use in decision and policy-making, even before full structural integration.

Integration by new lines entries, the second phase, comprises structural integration by introduction of line entries relevant to soil mining and erosion into conventional economic accounts.

BOX 1
System account divisions and entities

Phase 1: Integrated accounting by adding satellite accounts

Conventional economic accounts
- Input-output statement
- Balance sheet
- Operating statement (Budget)
- Cash flow

Nutrient accounts as satellite accounts
- Nutrient accounts in physical terms
- Nutrient accounts in monetary terms

Phase 2: Integrated accounting by new lines entries

Main accounts
- Nutrient input-output statement
- Integrated balance sheet
- Integrated operating statement (Budget)

Intermediate accounts
- Nutrient asset accounts
- Conventional economic accounts

As indicated above, integration by addition is the first and necessary step of the change in the quality of the soil accounting development and integration process. The major part of the computation work is done once this stage is completed. Structural integration comprises the simple transfer of a limited number of entries from the newly established nutrient accounts to conventional accounts. In the following sections both phases are treated in more detail.

Box 1 above summarizes the accounting divisions and entities under each of the two phases.

INTEGRATED ACCOUNTING BY ADDING SATELLITE NUTRIENT ACCOUNTS

Table 2 presents a matrix of the accounting system based on addition of accounts, with the account entities as columns and the levels and themes of analysis as rows. The account entities division consists of six entities under two categories of accounts: four conventional economic accounts and two satellite accounts (nutrient flows in physical and economic terms).

The composition of the conventional economic account subdivision is consistent with the fundamental structure and provisions of the current systems as critically reviewed in the present study. the review of the current accounting system shows that to assess financial performance, the system provides for data summary and analysis essentially in the four above-named statements (input/output statement, balance sheet, operating statement and cash flow).

As for the nutrient asset flow satellite accounts, they include two entities, nutrient asset statement in physical terms and nutrient asset statement in monetary terms, resulting from calculations described in Chapters 3 and 4.

TABLE 2
Accounting matrix for integration by addition of satellite accounts

Level of analysis	Account division					
	Conventional accounts				Nutrient satellite accounts	
	Input / output	Balance sheet	Budget	Cash Flow	Physical terms	Value terms
Crop model	X		X		X	X
Area/household /Farming system	X	X	X	X	X	X
(Sub)project	X	X	X	X	X	X
Environmental impact (land and soil)					X	X

Concerning the levels of analysis, within the framework of forward planning related to project ex ante analysis, the World Bank and FAO distinguish five indicative levels of analysis: crops, area models, farm household models, subprojects and projects. These levels are taken up here. An additional sixth, thematic item of analysis has been included: environmental impact assessment (EIA).

The account entities and levels of analysis in the matrix are indicative. To suit a particular purpose, the user can bring in additional accounts, e.g. labour, or other levels or themes of analysis, e.g. watershed or a given technology.

Conventional economic accounts

The conventional accounting system does not provide for records regarding environmental impact assessment or natural resources use. Emphasis is put on output maximisation. However, in terms of structure and levels of analysis, it presents a double interest for integrating soil nutrient accounts into conventional microeconomic or farm accounting. On the one hand, there is an account showing the scheduling of the physical inputs, e.g. fertilizer, required for each enterprise on the farm and for the farm as a whole. On the other hand, through aggregation it provides a transition framework for moving up from a single crop model to cropping pattern, rotation system, farming system, farm or farm household income, area model and agricultural project analysis. Thus, such a framework is useful for aggregation and statistical inferences.

The statements related to conventional economic accounts are established from either an *ex post*, backward-looking (accounting) view or an *ex ante*, forward-planning perspective[1]. The various statements are briefly described below.

The input/output statement is useful for all levels of analysis. For production models it shows input and output coefficients, e.g. yields, inputs and labour used for each crop and activity. For area or farm household models and subprojects or projects it summarizes data

[1] In forward-planning summary statements, the farm model concept is widely used. Particular reference is to made to FARMOD, a computerized data processing software developed by the World Bank and intended to be used by the Bank and the FAO Investment Center under the FAO-World Bank Cooperative Programme for enhancing project development and analysis through the farm model concept. FARMOD provides for seven summary tables (accounts) and five levels of analysis. Though the farm model as a concept is widely used, FARMOD application software appears to be much less widely used and in decline, even within the World Bank. Its use within FAO's Investment Centre has been generally confined to data processing and tabulation for planning budgets as defined above, physical input/output coefficients and financing (credit) budgets. FARMOD's relative complexity and rigidity appear to have led many users to prefer more flexible spreadsheet tools.

in quantitative terms on cropping intensity, cropping patterns (including rotation systems), production, input and labour use.

The balance sheet is a summary of assets and liabilities characterizing the farm business at a particular time, generally covering a one-year period. Assets accounts are a listing of capital goods owned by the business and their values. Capital goods include such items as farm machinery, buildings and productive animals. Capital goods are recorded at their original cost, and then the accumulated allowance for depreciation is deducted. In conventional accounting, land and soil are never depreciated. Liabilities represent the claims against the assets owned by the business. It is in the nature of asset accounts to provide a measure of the financial status and economic performance of a business over time.

The operating statement is also referred to as income statement or real-level budget. The term operating statement is used in this study. It is a summation of the farm business revenues and expenses over some period, showing the financial outcome (profit or loss for the business) and providing a measure of the net return to capital, equity, family labour and management. The concept of rate of return to the natural capital such as land is not present. Revenues represent the value of all farm-produced goods and services during the accounting period as well as non-operating cash receipts such as subsidies and interest received. Expenditures include cash operating and non-cash operating expenses such as depreciation and non-operating expenses (an example in table 8).

The sources-and-uses-of-funds statement (cash flow) shows when and from where money comes in to the farm business (cash inflow) and when it goes out (cash outflow) over some period. The statement reflects the business liquidity position and helps ensure that there is enough cash to cover expenses when needed.

Structure and functions of the satellite nutrient flow accounts

Physical satellite accounts

In several countries, institutes have been carrying out studies to measure nutrients flowing into the soil and out of it through various processes. Presenting these data in currently used accounting structures may enhance their use in decision making. Table 3 shows such a detailed structured account of nutrient flows in physical terms for a hypothetical farming model.

Because of the difficulties in quantifying the stock of nutrients contained in the soil and economically exploitable at any point in time, the nutrient asset account is limited to recording changes in the stock of nutrients during the accounting period with unknown opening and closing balances. Changes in the stock of nutrients summarize inflow accounts (natural inflows, fixation by crops, organic manure, purchased mineral fertilizer, residues returned to the land) and outflow accounts (uptake by harvested products and crop residues, erosion losses and other losses such as leaching, gaseous losses). Opening and closing balances imply a business account series extending over at least two years.

Establishing these physical accounts constitutes the first step in the implementation process. The analyst will rely on technical nutrient data and farm management resource data available in relevant ministries and associated research and cartographic institutes, appropriate agricultural surveys and censuses, land use statistics, and relevant records kept by local public authorities. Data that are not available will have to be acquired (observed, measured or estimated) as a preliminary step.

TABLE 3
Physical nutrient asset accounts (kg/ha/year)

	N	P	K	Ca	Mg
Opening balance	X_N	X_P	X_K	X_{Ca}	X_{Mg}
INFLOW	25.4	4.1	27.4	27.4	9.1
Natural inflow	10.0	2.1	6.9	20.1	4.9
Fixation by crop	1.4	0.0	0.0	0.0	0.0
Organic manure	0.7	0.1	0.9	0.5	0.2
Mineral fertilizer	0.1	0.1	0.1	0.0	0.0
Restituted residues	13.2	1.8	19.5	6.8	4.0
OUTFLOW	54.9	8.3	36.7	30.9	12.3
Crop	9.9	4.1	-8.6	10.5	-0.4
Stover	21.4	2.6	32.9	10.3	6.6
Erosion losses	9.2	1.4	10.5	7.9	4.7
Other losses	14.4	0.1	1.9	2.2	1.4
BALANCE (-) OR (+)	-29.5	-4.2	-9.3	-3.5	-3.2
Closing balance	X_N - 29.5	X_P - 4.2	X_K - 9.3	X_{Ca} - 3.5	X_{Mg} - 3.2

Note: The mineral fertilizer inflow entails a negative lime inflow (acidification) equivalent to 1 kg/ha/year.

Nutrient asset accounts in monetary terms

Nutrient accounts in physical terms allow for technical sustainability analysis. To allow for integrated environmental and economic analysis, they should be expressed in monetary terms. The physical flows are valued by the replacement cost method as described in Chapter 4 to convert them into monetary terms. This conversion constitutes the second step in the implementation process. Similarly, the value of an overall nutrient deficit (net depletion) or surplus (net accumulation) can be calculated as the sum of the values of the specific elements (it could include lime, if it is required in order to prevent acidification). This sum is called the nutrient balance market value (NBMV), mathematically defined (Stocking 1986) as:

$$NMDV = \sum_{i}^{N, P, K, Ca, Mg, CaCO_3} B_i \text{ x } V_i$$

where

B_i = the deficit or surplus of an element in kg/ha, and

V_i = the market value of that element in currency/kg.

The value of the nutrient deficit is reflected as a contribution from the natural nutrient stock in the soil to the agricultural production process. Since it involves a decrease in the value of the soil nutrient stock, it may be considered as soil capital consumption, an environmental cost.

Deficit values can be calculated for each crop, and compared to crop budgets. Crop data can be aggregated to give results for representative farm models (specific crop rotations or production systems). Results of typical farm models can be aggregated to give results for

TABLE 4
Nutrient asset accounts in monetary terms (US$/ha/year)

	Total	N	P	K	Ca	Mg
Opening balance	X_T	X_N	X_P	X_K	X_{Ca}	X_{Mg}
INFLOW	85	40	7	38	0	0
Natural inflow	23	12	2	9	0	0
Fixation by crop	2	2	0	0	0	0
Organic manure	9	4	1	4	0	0
Mineral fertilizer	14	9	2	3	0	0
Returned residues	37	13	2	22	0	0
OUTFLOW	136	70	6	60	0	0
Crop	24	16	2	6	0	0
Stover	57	19	2	36	0	0
Erosion losses	31	14	2	15	0	0
Other losses	24	21	0	3	0	0
BALANCE (-) OR (+)	-51	-30	+1	-22	0	0
Closing balance	X_T - 51	X_N - 30	X_P + 1	X_K - 22	X_{Ca}	X_{Mg}

Note: Where fertilizer application entails acidification, the value of the equivalent amount of lime should be included as a negative inflow.

farm households and these can be aggregated to give results for specific ecological zones and subsequently to subproject, project, region and country aggregates. In the process a variety of analytical ratios can be calculated for use in decision making at multiple levels. A nutrient flow summary statement in monetary terms (Table 4) would normally have a format similar to that for physical accounts.

INTEGRATING ACCOUNTS BY INTRODUCTION OF NEW ENTRIES

The principal feature of integration into accounting of environmental degradation through soil mining and erosion is the inclusion of an allowance for *depreciation of natural assets* on the basis of the value of depleted nutrients. As is the case with depreciation of other productive assets, depreciation of the quality of soil defines the level of an allowance that should be reserved to ensure sustainability of services provided by the soil. As with normal depreciation, it may not be optimal or effective to substitute depleted nutrients by the same fertilizer that was used for establishing the level of the depreciation allowance. Probably a more complex combination also including soil conservation measures and cropping practices will be needed to ensure future productivity of soils.

Because depreciation (including that of land quality) does not represent a cash outlay, it is not an item in the cash flow statement.

The accounting structure proposed to allow for the above mentioned entries is presented below. The matrix shows the account entities division (columns) and the relevant levels and themes of analysis (rows).

TABLE 5
Integrated accounting matrix after introduction of new entries

Level of analysis	Account division				
	Integrated accounts			Intermediate accounts	
	Inputs/outputs including nutrients	Integrated balance sheet	Integrated budget	Nutrient accounts	Conventional accounts
Crop model	X		X	X	X
Area / household / Farming system	X	X	X	X	X
(Sub)project	X	X	X	X	X
Environmental impact (land and soil)	X	X	X	X	X

The integrated account entities division is shown to consist of three entities under a single category, the integrated economic-natural resource accounts. The composition of the integrated accounts is identical to that of the conventional economic accounts presented in table 2 above. Non-integrated accounts, e.g. cash flows or credit accounts, are not included here.

New entries are introduced into three conventional accounting statements to make them integrated summary statements in physical terms (integrated input/output statement) or in financial terms (integrated balance sheet and integrated operating statement or budget).

The detailed nutrient asset statement in physical terms and the detailed nutrient asset statement in monetary terms that were considered as satellite accounts in the previous phase, become intermediate accounts in the integrated accounting matrix (Table 5).

From a real accounting view, these statements are backward-looking summations in physical and monetary terms of what did really happen. From the forward planning view, they become projections reflecting what is planned to be achieved. From this view, the same account entities remain, preceded by the word projected, except for the operating statement, which becomes the planning budget.

In the following sections the integrated nutrient/input-output statement, the integrated balance sheet and the integrated operating statement are described in more detail.

Integrated nutrient input-output statement

The input-output statement in physical terms as existing under the current accounting system is integrated through the introduction of a new entry in terms of nutrients as a means of extending the concepts of economic value and cost associated with fertilizer –marketable nutrients–, to nutrients provided by nature (Table 6).

The integrated nutrient input-output statement shows new entries including environmental impact (under output), and identified nutrients provided by the environment.

The integrated balance sheet

Consistent with the concept of integration by new entries, natural resource accounting elements are introduced into the conventional balance sheet. Four new entries are thus integrated into one in the fixed asset section of the statement (shaded area). This summarizes in monetary terms the change in soil quality over one year, in terms of nutrient depletion or nutrient accumulation as measured in the nutrient flow accounts. The net change (nutrient balance) is recorded as net capital consumption (Table 7).

TABLE 6
Integrated nutrient input-output statement

	Unit	Crop 1	Crop 2	Crop 3	Crop …
Inputs (Quantity)					
Purchased					
Seeds					
Fertilizers (1,2,3..)					
Hired labour					
…					
Nutrients provided by nature					
N					
P					
K					
Other					
Outputs (Quantity)					
Yield					
By-products					
Non marketed					
Residues					
Fertilizer-induced pollution					
Other					

TABLE 7
Integrated balance sheet (in US$ for a hypothetical farm model of 3 ha)

	Conventional	Integrated
Current assets		
Cash and bank	250	250
Others	450	450
Total current assets	700	700
Fixed assets		
Building and equipment	1500	1500
Less depreciation	-450	-450
Land and soils	pm	pm
Less change in soil quality (depletion)		-150
Net fixed assets	1050	900
Total assets	**1750**	**1600**

The integrated operating statement

As for the integrated balance sheet, new natural resource accounting entries are introduced into the conventional operating statement. Three new entries are thus integrated into the non-cash expenses (or depreciation allowance) section of the conventional operating statement (shaded area). Derived from the integrated hypothetical balance sheet, which assumes net nutrient depletion, they summarize in value terms the impact of such depletion on farm income in time perspective. Net depletion or the negative nutrient balance, recorded as natural capital consumption in the balance sheet, appears here as a cost in terms of nutrient substitution or allowance for nutrient replacement. When actually incurred, such cost will reduce the recorded farm income by an equivalent amount down to the net adjusted (sustainable) income level (Table 8).

TABLE 8
Integrated operating statement (in US$ for a farm model of 3 ha)

Items	
Revenue	
Sale of products	480
Other	120
Total revenue	600
Expenses	
Cash expenses	
Fertilizer	70
Seeds	15
Other	40
Total cash expenses	125
Income before depreciation	475
Non-cash expenses	
Depreciation allowances	
Building and equipment	80
Net Income before allowance for nutrient replacement	**395**
Allowance for nutrient replacement	**150**
Net adjusted (sustainable) income	**245**

New entries as described imply that the assessment of the financial position of the farm business as expressed in the relevant financial statements will systematically reflect the benefits and costs related to all the capital resources involved, whether they are produced and marketed or simply provided by natural capital – soil in this particular case.

In particular, the integrated balance sheet and operating statement will provide several major benefits. In particular, they will:

- Provide a more comprehensive and accurate measure of the value added and the performance of the business during an accounting period. In the hypothetical case discussed above and from the sustainability viewpoint, the net farm income is overestimated by US$ 150 (about 38 percent) in conventional accounting in comparison to integrated accounting.
- Enable the user to better assess the net capital formation and retained earnings; retained earnings are an excellent indicator of farm generated financial progress. In the hypothetical example presented for illustration, net fixed assets are overestimated by US$ 150 (14 percent) in conventional accounting and retained earnings are in fact shrinking.
- Introduce into the analysis of farm business assets the concept of fixed capital consumption and its replacement allowance as a condition for ensuring sustainability in land use and productivity.
- Help ensure that natural assets are treated in the same way as produced assets.
- Enhance the notion of sustainability standards into the concept of integrated accounts, already inherent in conventional farm income accounting.
- Allow for the establishment of a variety of ratios and indicators useful for integrated farm business management.

EXAMPLES FROM CASE STUDIES

With the objective of verifying the appropriateness and applicability of the methodology in various situations, case studies were undertaken at several locations (summaries in Chapter 6). An example of the valued nutrient accounts and integrated economic and environmental accounts drawn from the results of one of the case studies is presented below to provide further insight into the accounting system (Tables 9 and 10).

TABLE 9
Valued nutrient accounts for small-scale cassava producers in a sub-catchment of the Salamaga river, Colombia (Col $/ha/year)

Small-scale cassava producers	Valued nutrient accounts for the small scale cassava (Col$/ha/yr)			
	Total	N	P	K
OPENING STOCK	**XS**	**XN**	**XP**	**XK**
INFLOW	**100 446**	**54 691**	**19 525**	**26 230**
Natural inflow	2 761	0	1 702	1 059
Fixation by crop	2 567	2 567	0	0
Organic manure	0	0	0	0
Mineral fertilizer	0	0	0	0
Returned residues	95 118	52 124	17 823	25 171
OUTFLOW	**154 250**	**80 748**	**35 333**	**38 169**
Harvested crop	26 888	11 108	8 416	7 364
Stover	109 663	59 217	22 044	28 402
Erosion losses	7 968	4 184	2 129	1 385
Other losses	10 001	6 239	2 744	1 018
NET NUTRIENT ACCUMULATION	**-53 804**	**-26 057**	**-15 806**	**-11 939**
CLOSING STOCK	**X$-53 804**	**XN-26 057**	**XP-15 806**	**XK-11 939**

TABLE 10
Integrated economic and environmental accounts for small-scale cassava producers in a sub-catchment of the Salamaga river, Colombia (Col $/ha/year)

Case: COLOMBIA	Size 14.45 ha			
Area: mountain/cassava	Type: small-scale cassava producers			
Revenues	Col$	Expenses	Col$	FAmily labour days
Crops		**Crops**		**254**
Value of product	**6 192 000**	**Fertilizers**		
Principal		Pesticides		
Value of by product				
Other activities		Other activities		
Transfers		**Equipment operation**		
		Maintenance		
Other		Debit service		
		Other cost		
Total revenues	6 192 000	General cost	774 000	
		Total days of family labour		254
Investment		Depreciation allowance		
Net income		Net income per day of family labour		
Before nutrient replacement	5 418 000	Before nutrient replacement	21 356	
Depreciation of nutrients	831 280			
Net sustainable day-income	4 586 280	Net sustainable day-income	18 079	
Sustainable % of income	85			

6. Analytical approach and implementation

Analysis of outcomes of the calculated physical and monetary accounts may provide insight both on sustainability issues and on conventional nutrient efficiency and fertility management. Two main kinds of analysis can be carried out: analysis of the internal structure of the nutrient accounts and analysis across the accounts coupled with the integrated balance sheet and operational statement analysis.

WITHIN-NUTRIENT-ACCOUNT ANALYSES

An analysis of the internal structure of the nutrient accounts can be an important step in assessing the strengths and weaknesses of soil nutrient management and, therefore, of soil use and fertility management. Four types of views or insights that can be provided by within-nutrient-account analyses are described below.

Sources and uses of nutrients: nutrient balances

Negative balances, which are implicitly recorded as consumption of natural capital through economic use or loss, imply a potential decrease in the short- or long-term productive capacity of the soil. Such balances are signals of need for remedial or defensive policy and action of one kind or another. Positive balances are implicitly recorded as capital formation or accumulation, suggesting sustainable use. But when associated with high soil losses they signal possible over-fertilization and related unnecessary costs, ground water pollution and inadequate soil management. Such balances are signals of the need and scope for action to improve soil resource use.

Nutrient inflow structure

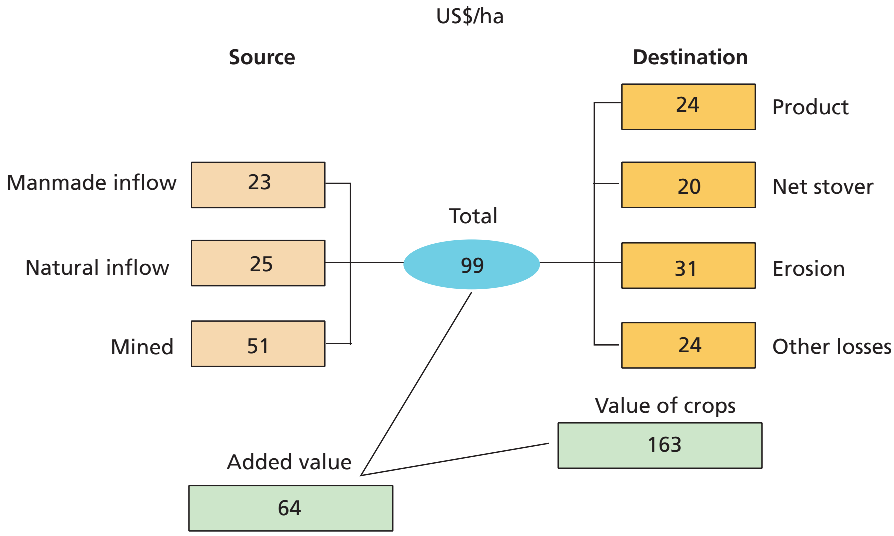
Comparing the value of paid and free nutrients may give an indication of the relative importance of fertilization in the maintenance of soil fertility, i.e. the degree to which the production system is dependent on natural processes. Since natural processes give a fixed contribution per ha, farmers in natural systems will tend to increase the extent of their cultivated area to harvest as much of the free nutrients as possible.

If the value of mined nutrients is compared with that of the sum of paid and free nutrients, an impression is obtained of the relative importance of soil mining in the production system.

Nutrient outflow structure

Comparing the value of all nutrients needed for crop production with the value of nutrients taken up by the harvested product may give an indication of the efficiency of the cropping system with respect to nutrients, and how much scope there is for measures to minimize avoidable losses. Finally, comparing the value of avoidable losses with the value of mined nutrients may indicate ways to prevent mining by implementing measures that reduce losses (in most cases anti-erosion measures).

FIGURE 7
Value of nutrient flows



Valued nutrient inflow and outflow accounts

Nutrient inflow and outflow accounts as included in Table 4 may also be presented as in Figure 7 for analytical purposes.

As the conventional balance sheet shows the type, amount and origin of resources put into a business and the destination of such resources, the nutrient flow balance sheet will show:

The origin of soil nutrients used for crop production (inflow) and what such nutrients are used for (outflow), in physical or monetary terms.

The impact of a particular production system and its cultural setting on the quality of the soil. Comparing the sum of all the uses and losses – destinations – with the sum of paid and free nutrients will give an indication of the extent of soil mining associated with the production process.

The real value added of agricultural production. This is obtained by comparing the cost of all the nutrients needed for crop production, regardless of the origin, with the relevant value of produced crops.

Explicit measures of negative or positive nutrient balances, comparing inflows and outflows.

Some direction as to ways to prevent soil mining, e.g. implementing anti-erosion measures. This is obtained by comparing the value of avoidable losses with that of the value of mined nutrients.

These analyses thus are of immediate use for improved soil management and policy decisions. Graphical presentations of the flow structure as in Figure 7 may help in this respect.

CROSS-ACCOUNT AND INTEGRATED ANALYSIS

Analysis across the accounts coupled with the integrated balance sheet and operational statement analysis can be carried out based on integrated indicators. These could focus on sustainability as well as on conventional farm management efficiency. Three ratios and indicators, briefly described below, can be calculated and analysed: the sustainability ratio, added value with respect to nutrients, and the productivity foregone and replacement ratio.

The sustainability ratio (SR) is calculated by dividing the net adjusted income by the net income before nutrient substitution. If, for example, the value of nutrient depletion in a production system would amount to 25 percent of the conventional net income (25 percent of the income can be considered as obtained through soil mining), the sustainability ratio would be 0.75.

Added value with respect to nutrients (AVN) is calculated by subtracting the value of all nutrients needed for crop production from the value of the produced crop. This gives an indication of the real added value realized by agricultural production. It may serve as an indicator for the possibility to intensify agricultural production in the given circumstances. Since two sources of nutrients (natural inflow and stocktaking) cannot be increased to make yields higher, only human-made, paid nutrients, can be used for intensifying crop production (Figure 7). Comparing the added value with respect to nutrients with the conventional added value reflects the drop in income when farmers have to intensify their production.

The productivity foregone and replacement cost ratio (PRR) is calculated by dividing the value of production which would be lost if the replacement of lost nutrients were not undertaken by the cost which would be actually incurred for the replacement. The replacement would be justified if PRR is greater than 1. The assessment entails the use of integrated cost/benefit analysis. This involves, in addition to the use of the replacement cost as provided here, valuation of production foregone through the change-in-productivity method as described in Chapter 4. Ratios smaller than 1 may represent a hint that maintaining soil fertility is not feasible for farmers. More cost-effective measures of maintaining soil fertility could be a solution (e.g. anti-erosion measures reducing nutrient losses are always worth being considered as preferable alternatives). Where these are no options, subsidies on soil quality maintenance seem necessary to transfer avoided social cost of soil degradation to farm households.

IMPLEMENTATION THROUGH CASE STUDIES

Five steps are involved in implementing the methodology (Van der Pol, 2004):

- Problem definition and preliminary selection of target areas
- Identification of partner institutes and work planning
- Information collection and handling
  - Data to be collected on farming systems
  - Biophysical data to be collected
- Computing and analysis
  - Checking availability and format of collected data
  - Workshop for joint computing and analysis
  - Definition of major interpretation issues
- Generating impact
  - Informing policymakers and civil society groups
  - Informing the scientific community
  - Expansion of the study to other areas or projects
  - Complementary research and surveys

Problem definition and preliminary selection of target areas

Actual problems with the maintenance of the productive capacity of land will vary from area to area or project to project. The first step is, therefore, to determine the geographic environment of an integrated environmental and economic accounting exercise. Since the methodology is based on the valuation of nutrient flows in soils, a major knowledge centre in this area should be associated with the problem-owning organization. This leading association of the problem owner and the coordinating knowledge institute would produce a statement of the problems that led to the formulation of the study and make a preliminary selection of target areas and representative farming systems

Identification of partner institutes and work planning

This phase starts with the identification of the institutions having detailed knowledge on the major soil nutrient flows in the selected areas, especially for the targeted farming systems. Good information on the farming systems in the region is equally important. Centres of knowledge in this field are to be identified as well. Preliminary information is needed on the data these institutions could provide and on their willingness to participate in the study. This phase would be concluded with the organization of a 2½-day workshop, inviting representatives of the potential participating knowledge centres. The workshop should lead to a work plan for each of the participating centres.

Information collection and handling

This stage is in fact the implementation of the first part of the work plan as defined by the participating institutions during the preceding workshop. Data to be collected by the farming systems group includes information on cropland use pattern, crop model production, crop model nutrient management, crop model inputs and joint inputs. Collection of biophysical data by the biophysical group could necessitate both collecting primary data and exploring secondary sources. Some of the required data are associated with farmers' practices, and could be collected as a part of specific farm surveys. However, most of the data –mainly data on soils, crops and fertilizers– are region-specific and should be found at specialized (research) organizations or institutes. Where these data are not available for the specific region, the approaches could include either interpolation of data from nearby similar regions or formulation of specific research programs on the missing data.

Computing and analysis

This phase comprises the implementation of the second part of the work plan defined by the participating institutions during the first workshop. The work will mainly consist of checking collected data, organizing a joint computing and analysis workshop with participating institutions, interpreting the information to respond to the issues and discussing further activities for impact generation.

Generating impact

At the end of the workshop for joint computing and analysis, the results will be sufficiently clear to define a number of future actions. Depending on the results, actions could include informing policy makers and civil society groups; informing other researchers; expansion of the study to other areas or ongoing projects or formulation of complementary research or surveys. As a basis for all future actions, the leading association should prepare a final report with detailed information on the process and organizational aspects of the study and with a description of the results obtained.

EXAMPLES FROM CASE STUDIES

The following paragraphs present examples from case studies conducted in Colombia, Costa Rica, Thailand and Bangladesh.

Colombia

In Colombia, the methodology of integrating environmental and economic accounts was implemented by a multidisciplinary team from National Corporation for Agriculture Research (CORPOICA), with technical assistance from the Agricultural Management, Marketing and Finance Service (AGSF), FAO.

The selected area, the Salamaga sub-watershed, is located in the east-Andean region of Colombia. The Salamaga sub-watershed covers 21 448 ha, mainly cropland and fallow. Smallholders, both owners and sharecroppers, are the dominant land users; they cultivate cassava and maize in rotation and use fallow systems. Another system is cocoa plantation, with intermediate technologies and larger land holdings. A conservationist model including rotation, live barriers and nutrient recycling has been tested in the region.

Selected farming systems comprise smallholder cassava, sharecropping cassava, smallholder cocoa and a conservationist model. The first two types of farming systems are highly extractive, given the system that is used in cassava production. This is because no fertilizer or amendment to correct acidity is applied and, when the crop is harvested, the entire plant is removed from the field. Interaction between crops and livestock activities is minimal; stock is not turned out to graze on the residues, nor is their feed supplemented with crop residues. Cattle are kept in corrals at night but the manure is not collected for use as fertilizers. Cocoa is a permanent and highly protective crop. However, the farming system currently in use, with very high applications of fertilizers, is undermining the short-term profitability of this crop. The conservationist system corresponds to a model implemented at a research station.

Primary outcomes from using the methodology are nutrient flows at the crop level for the most important elements (N, P, K, Ca, Mg and S). They are calculated in physical (nutrient inflows and outflows) and monetary terms (valued nutrient inflow and outflow accounts). An aggregated value of these outcomes per crop and per rotation system can be obtained. Finally, the results of the nutrient balance at the farm level can be summarized.

The findings illustrate the rationale used by cassava farmers within a completely extractive, yet highly profitable production system. However, that profitability ignores a hidden opportunity cost that is equivalent to the cost of the nutrients that farmers extract from their land and do not replace. When this cost is factored into the production costs of the farm, the levels of profitability and of sustainable income are lower.

Figure 8 shows the valued nutrient flows at the farm level in the smallholder cassava farming system. Here 89 percent of the nutrient outflow is removed by the plants, 5 percent is lost by erosion, 4 percent by leaching and 1 percent by denitrification. Sixty-two percent of the value represented by these nutrients is returned to the system, primarily by natural recycling in fallow fields; 2 percent is returned to the system by rainfall and another 2 percent by nitrogen fixation.

It is important to note that the 34 percent of the nutrient value taken out of the systemand not returned is not counted as a production cost. In monetary terms, farmers are drawing out Col $ 53 805 per hectare per year, which at the farm level represents a loss of Col $ 831 280 per year because of nutrient extraction (Figure 9).

A comparative analysis of the farming systems performance, which incorporates the results of nutrient flows into the conventional accounts, is presented in Table 11.

FIGURE 8
Distribution of valued nutrient flows for the small-scale cassava farming system, Colombia

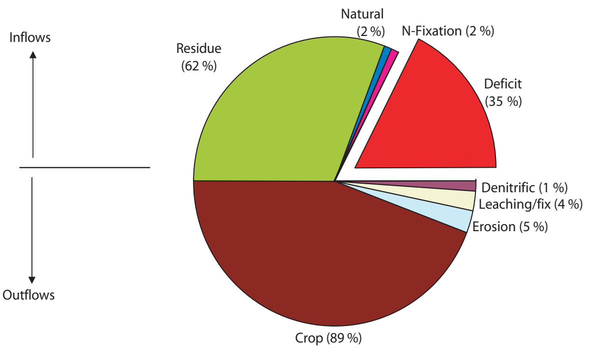
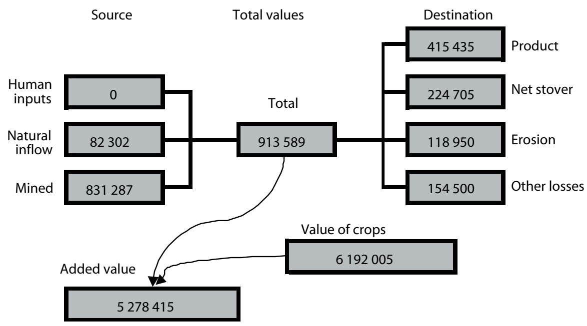


FIGURE 9
Small-scale cassava farming system – value of nutrient flows, Colombia (Col $/ha/yr)



In the smallholder cassava farming system, the income level before nutrient depreciation is equivalent to Col $ 21 331 per day of work on the farm, which is higher than the going daily wage in the area and above the official minimum wage in Colombia. At Col $ 5 418 000 per year, household income levels could be considered satisfactory. For a family of five, this is equivalent to US$ 1.14 per day (i.e., above the one-dollar-a-day threshold).

The profitability level of the farm drops substantially when the extraction of nutrients is taken into account. In fact, Col $ 831 280 worth of nutrients that are taken out of the system represents 15 percent of the total value of cassava sales. This means that the farmer's actual income is not Col $ 5 418 000 per year, but rather Col $ 4 586 720 per annum. The sustainable income would be equal to 85 percent of the apparent income. The equivalent wage for the 254 days worked on the farm is thus Col $ 18 057, which is still higher than the going wage in the zone. In terms of per capita income per year, for a family of five, small-scale cassava farmers are thus earning US$ 0.96 per day, which places them below the poverty line.

The sharecroppers' farming system is less profitable and even more extractive than the smallholders' as they do not have enough time for crop rotation involving fallowing practices, which would serve as a natural nutrient recycling system. When the economic value of the extracted nutrients is integrated into the accounts, the results show that the tenant farmers are earning less than the current daily wage in the country.

In the sharecropping farming system, the position of the landowners is more contradictory. Their lands are losing nutrients with a value equivalent to half of the rent they receive from their tenants. Thus, their sustainable incomes are only half of the amount they receive. They are exchanging capital for an unsustainable monetary flow.

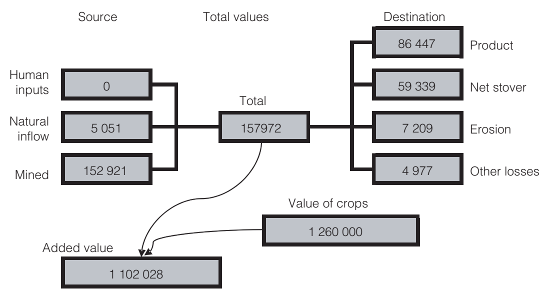
Nutrients equivalent to Col $ 458 764 are extracted from the soil per year in a just three hectares plot, which generates a 75 percent nutrient deficit (Figure 10). In terms of value, 94 percent of the nutrients are removed by the crop; 4 percent is lost through erosion and 2 percent through leaching. About 22 percent of the value of these nutrients is returned to the system through the nutrient replacement that occurs while the field is fallow and the natural recycling action of fallow fields; 1 percent of the nutrient inflows are generated by natural causes such as rainfall, and another 1 percent comes from N fixation. The major difference lies in the use of fallow fields and fallowing, which permit greater recycling and soil recovery in

TABLE 11
Integrating nutrient flows into farm economic accounts, Colombia

Items	Farming system			Model
	Smallholder cassava	Sharecropping	Cocoa	Conservationist
Revenues	6,192,000	3,780,000	5,990,400	20,099,264
Expenses	774,000	1,384,000	939,698	3,146,803
Net income before nutrient depreciation	5,418,000	2,384,000	5,050,703	16, 952,461
Depreciation	831,280	458,764	299,820*	824,853
Net sustainable income/ year	4,586,720	1,925,256	5,350,522	16,127,608
Family labour (days)	254	159	267	360
Net sustainable income/day	18,057	12,108	20,039	44,762

Note: Data in Col $ (1 US$ = 2480 Colombian $).
*Positive values are added instead of subtracted from the net income
Source: Santacoloma *et al.*, 2005.

FIGURE 10
Values of nutrient flows for the sharecropping farming system, Colombia (Col $/ha/year)



the case of the smallholders owning their land. The bulk of this cost corresponds to nitrogen losses. Nitrogen inputs into the system are reduced proportionally, both in the case of nitrogen fixation and in that of natural inflows, but the main factor in this reduction has to do with replacement through crop residues, since the time periods allowed for fallowing and fallow fields are short.

The total earnings are clearly insufficient for subsistence. The conventionally calculated farm income of Col $ 2 384 000/year is equivalent to a daily income of US$ 0.5 per person for a family of five. This means that the members of these families are below the extreme poverty line. If calculations on nutrient depreciation were including, the economic performance per family member would be even worse.

The situation with respect to cocoa production runs counter to widespread belief. It is not as profitable as cassava production under current management conditions. In the cocoa farming system, the results suggest that the farmers are wasting money on excessive fertilization, and indicate the importance of carrying out a more detailed study on the fertilization of cocoa crops. The owner of the crop works 267 days a year; this yields a daily wage equivalent to Col $ 18 916, which is higher than the going daily wage in the area. In terms of annual household income, for a family of five this level of income is equal to US$ 1.06 per day per person, which is above the poverty line. These figures would be higher if nutrient depreciation, which is positive (enrichment), would be included.

In the conservationist model, the nutrient flows indicate that the loss of nutrients is similar to the loss recorded for the small-scale cassava farming system, although the profitability level is four times higher. Based on the technical recommendations, Col $ 898 309 worth of mineral and organic fertilizers is applied per year. It is important to note that the nutrient deficit per cultivated hectare represents 23 percent of the value of the cycled nutrients. Here again, the major nutrient component is nitrogen, which accounts for nearly 50 percent of the nutrient loss.

In this model, annual income rises to Col $ 16 952 461. This is equivalent to a daily wage of Col $ 47 051, which is more than three times the going wage in the area. For a family of five, this yields an income of US$ 3.56 per person per day, which is three times higher than the poverty line. Accounting for nutrient depreciation would reduce slightly this figure to US$ 3.38 per person per day.

The project shows that the model of crop rotation using live barriers provides higher income levels in the short run and is beneficial both from an economic standpoint and in terms of sustainability. Using rotation and low fertilization levels, experiments have yielded high productivity rates that translate into a 95 percent sustainable income – even though the rate of nutrient depreciation is similar to that in the smallholder system.

Costa Rica

In Costa Rica, the participating institutions in the Ministry of Agriculture and Livestock were the Department of Central Agricultural Conservation, the Research Department, and the Bureau for the Central-Eastern Region. The Agricultural Management, Marketing and Finance Service (AGSF), FAO provided advisory assistance, funding and training facilities for the study; the FAO office in Costa Rica extended assistance in project funding management.

The areas selected are located in the Reventazon watershed in the central region, where intensified smallholders agriculture is predominant. The major land uses are crops, grassland and some forest. The Birris sub-watershed covers nearly 1 240 ha and is located between 1800–2300 m above sea level. Smallholders cultivate vegetables such as potatoes and carrots. The erosion rate is calculated to be 27 ton/ha/year. The other area, Reventado sub-watershed, occupies an extension of around 600 ha and is located between 2000–2500 m above sea level. The farming system comprises onion and, in minor quantity, potatoes. Erosion rates reach 22 t/ha/year. In both the regions soil conservation practices have been implemented.

Four farming system were identified, based on geographical location and frequent agricultural practices: Birris traditional and conservationist and Reventado traditional and conservationist. The main features of the traditional systems are tillage using disk harrows; planting down the field slope; fertilization based on the advice of agrochemical salespersons; and tillage and planting on bare soils. The conservationist systems are characterized by ploughing using a chisel instead of a disk; tillage and planting across (perpendicular) to the field slope; fertilization after soil analysis; and maintaining a residue cover during planting and field cultivation.

In terms of nutrient flows, the results show enormous application surplus of nitrogen, phosphorus, and calcium in both of the systems and sub-watersheds. However the higher surplus were found in the traditional systems, e.g. Birris traditional farming system registered a surplus of 28 percent N, 24 percent P and 14 percent Ca (Figures 11 and 12).

In contrast, a deficit of potassium (K) can be seen in all the systems. The greatest K deficit is found in the Reventado conservationist farming system. One reason may be the high K demand of potatoes and carrots. Besides this, the potassium losses are great in this system (Figure 13): around 31 percent of K outflow is lost through leaching and erosion.

The traditional farming systems have relatively higher variable costs than the conservationist ones because of greater use of fertilizer and pesticides and higher labour use (Table 12).

FIGURE 11
N flows in traditional and conservationist Birris systems, Costa Rica (kg/ha/year)

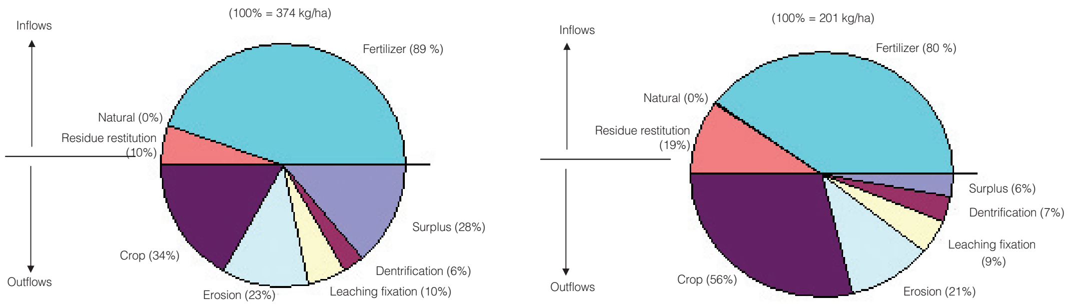


FIGURE 12
P flows in traditional and conservationist Birris systems, Costa Rica (kg/ha/year)

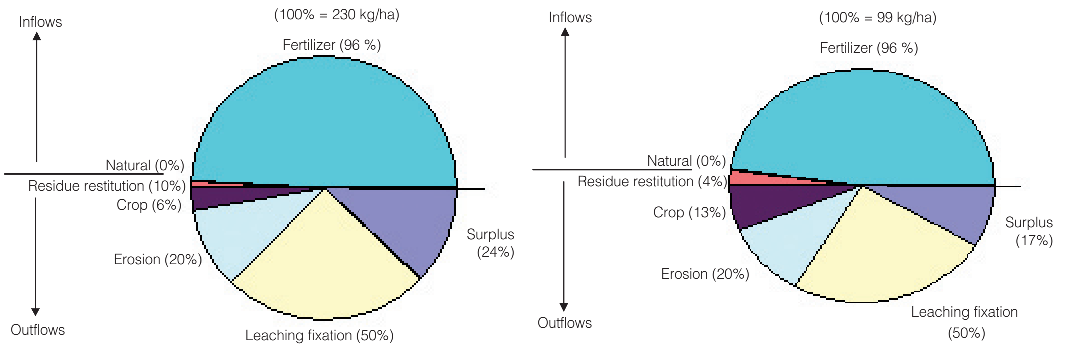


FIGURE 13
K flows in traditional and conservationist Reventado systems, Costa Rica (kg/ha/year)

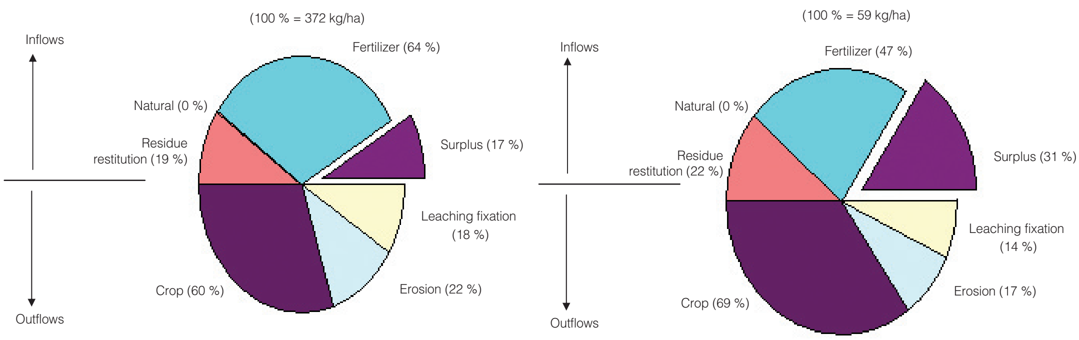


TABLE 12
Land quality changes integrated into farm economic accounts, Costa Rica

Items	Farming system			
	Birris traditional	Birris conservationist	Reventado traditional	Reventado conservationist
Revenues	2 018 599	1 640 715	3 704 550	649 796
Expenses	1 639 462	941 151	1 994 227	240 960
Net income before nutrient depreciation	379 137	699 563	1 710 323	408 836
Depreciation	24 439*	8395	5640*	2233
Net sustainable income/year	403 576	691 169	1 715 963	406 603
Family labour (days)	108	50	121	13
Net sustainable income/day	3736	13 823	14 181	31 277

Data expressed in Costa Rican Colon; (1 US$ = 484 Costa Rican Colon).
*Positive values are added.
Source: Santacoloma *et al.*, 2005.

In absolute terms, the conventional systems obtained a higher gross margin than the conservationist ones, probably because of the lower yields in the initial adoption phase of the conservationist system.

In the traditional systems there was a nutrient surplus instead of nutrient depletion, which is reflected in a sustainable income ratio above 100 percent. Substantial nutrient losses resulting through erosion and leaching, as shown through the nutrient balance studies, may be a contributing cause for water pollution downstream in the region.

Because of the large differences in family labour use between traditional and conservationist systems the sustainable incomes per day are not comparable.

Thailand

A country case study using integrated economic and environmental accounting was initiated in 1998 in Ubon Ratchathani Province, Northeast Thailand. It was carried out jointly by the International Board for Soil Research and Management (IBSRAM) and the Ubon Ratchathani Rice Research Centre (URRC), Department of Agriculture, Thailand. The work was one of the first studies during the development of the IEEA methodology.

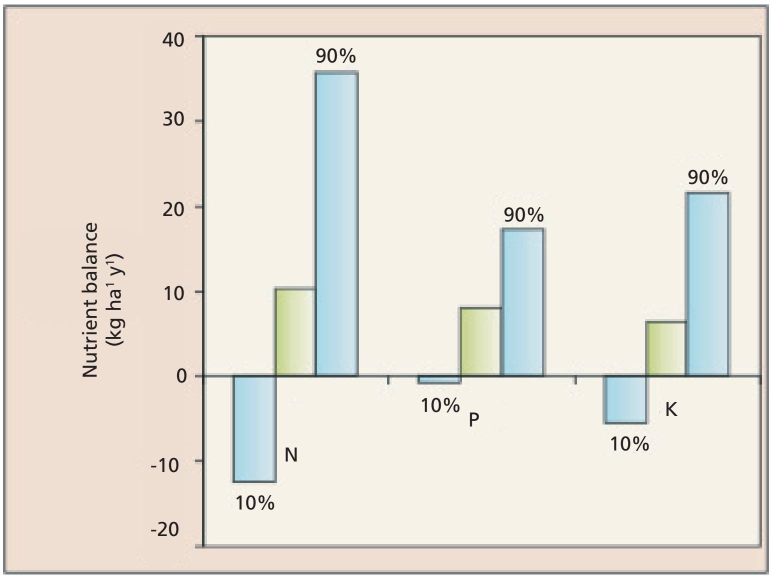
Partial nutrient balances, as derived in the Thailand case study, may serve as indicators of sustainability if considered with caution. The case study presented here excludes calculations relating to inputs through biological N-fixation, wet and dry deposition of N, P and K, sedimentation, and losses through leaching, erosion, runoff and gaseous emissions. The relatively simple assessment of partial nutrient budgets may be useful, especially if balance factors that are not included are judged with a combination of local and expert knowledge.

The study focussed on farms with rainfed lowland rice-based land use systems (LUS), which are dominant in the province and the region. The production systems of the surveyed farms are broadly similar, but there is a wide range in rice production, nutrient use, and other farm characteristics. Nutrient inputs, as fertilizer and organic materials, averaged 39, 16, and 16 kg /ha/year for N, P, and K, respectively. All farms used fertilizers and all but two applied organic materials. No fertilizer or organics were used on one LUT and organics were applied to only two-thirds of the LUTs. There was a large variation in yields and nutrient application rates between farms and, even more so, between LUTs.

TABLE 13
Partial N, P and K balances for rice-based systems, Thailand (kg/ha/year)

Partial balance	Farms			LUTs		
	n	Mean	SD	n	Mean	SD
N	30	12	17	75	11	23
P	30	8	6	75	8	8
K	30	7	9	75	8	15

FIGURE 14
Mean partial N, P and K balances for 75 LUTs from 30 farms, Thailand
With 10 and 90 percentiles



Mean partial N, P, and K balances for the rice-based systems were found to be 12, 8 and 7 kg/ha/year respectively (Table 13, Figure 14). Large variations in nutrient balances exist among different farms and land utilization types. Many negative partial balances were observed.

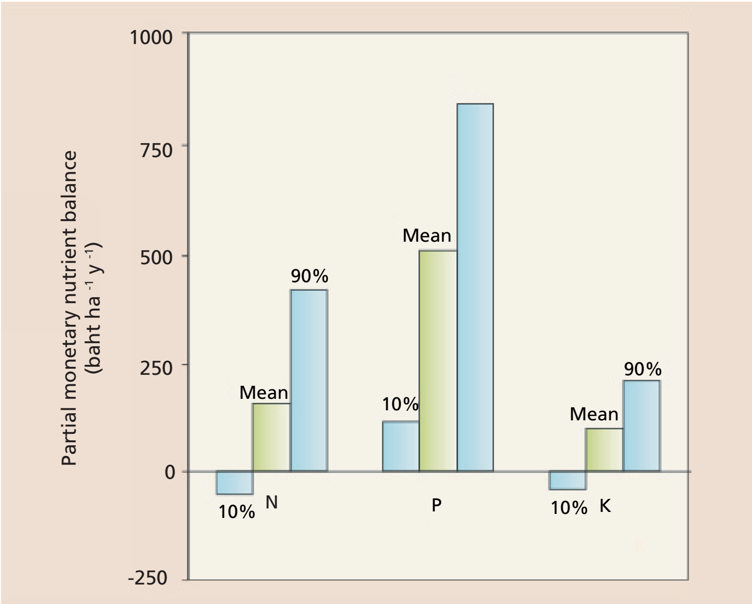
Farmers manage nutrients for similar parcels of land in very different ways, which results in a large variation in the partial nutrient balance, even for the same type of land use within the same farm. These results indicate high inter-farm and intra-farm variability for partial N, P, and K balances.

The study has shown that the proportions in which macro-nutrients are applied to the system are imbalanced. Farmers tend to invest about twice as much in P than in N (and twice this in K). Monetary partial N, P and K balances (Figure 15), show that especially for P the partial monetary balance is highly positive at the farm level.

Bangladesh

In Bangladesh, the National lead partner institution was the Bangladesh Soil Resource Development Institute (SRDI), a unit under the Ministry of Agriculture. SRDI acted as

FIGURE 15
Monetary values of partial N, P and K farm balances for 30 farms, Thailand

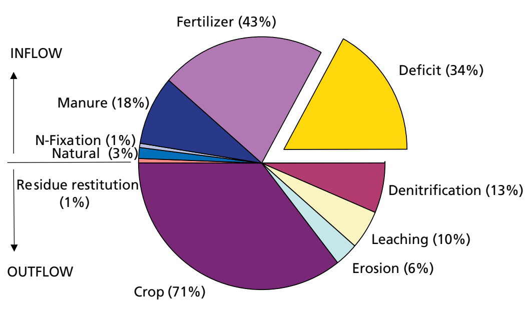


Source: Based on average market prices of nutrients (exchange rate 1 US $ = 41 Thai Baht). Including 10 and 90 percentiles.

an operating research unit, providing its own set of data. It also acted as coordinator of overall data collection and reporting carried out under the responsibility of five specialized research institutes, including the Bangladesh Agricultural Research Council; the Bangladesh Jute Research Institute; the Bangladesh Agricultural Research Institute; the Bangladesh Agricultural University; and the Department of Agricultural Extension, Ministry of Agriculture.

Figure 16 shows the valued nutrient nitrogen flows on medium highlands in Muradnagar district. Here the crops remove 71 percent of the nitrogen, 6 percent is lost by erosion, 10 percent through leaching and another 13 percent by denitrification. Of the value represented by these nutrients, 43 percent is made available to the system through mineral fertilizers, 18 percent through manures, 1 percent through N fixation and 3 percent through natural processes, leaving a substantial deficit.

FIGURE 16
Structure of nitrogen flows on medium high lands in Muradnagar District, Bangladesh



Considering the results of the case study, in particular the establishment of nutrient accounts in quantitative and value terms, the many potential uses that can be made of the accounts and the issues associated with required data generation and collection, the participating national institutes listed above assessed the methodology as a timely and useful tool in accounting for changes in land and soil quality on the basis of net nutrient depletion and accumulation. They also found that since the methodology provides desirable details concerning the various causes or sources of nutrient inflows and outflows, it appears particularly appropriate for improved soil productive capacity analysis and for sustainable management and use of land and soil as natural capital.

7. Potential applications

PARTICIPATIVE METHODS FOR SOIL FERTILITY MANAGEMENT

Participatory approaches are an effective way to investigate issues of concern to people; to assist them in the process of visualizing and formulating their needs and opportunities and in the action required to address them; and in planning, implementing and evaluating development activities.

Soil fertility management is particularly suited to this type of collaborative interaction and learning since it involves many issues that are complex and not directly observable, such as chemical aspects underlying soil fertility processes (Defoer & Scoones 2000). Popular methodologies for soil fertility management based on participative methods include approaches such as farmers' field schools (FFS, FAO 2000) and participative learning and action research (PLAR, Defoer 2000). However, in contrast to the PLAR approach, the FFS approach does not explicitly deal with diversity and does not build on a long-term engagement of farming communities. In contrast to FFS, PLAR also explicitly distinguishes communicative and individual learning. Annex 1 describes PLAR in some detail and briefly touches on its application to nutrient balance studies.

Studies in sub-Saharan Africa (Penning de Vries & Djiteye 1982, Defoer *et al.,* 2000) have shown that assessment of nutrient balances is a powerful tool for evaluating the sustainability of agro-ecosystems at different scales. Nutrient balance principles can be linked to socio-economic data and can be used to develop improved recommendations aimed at both the biophysical and socioeconomic aspects of sustainability. Nutrient budgets have a significant educational role in farmer participatory research and participatory extension methods. Expressed in monetary terms they can serve as a template for economic accounting and financial assessment of nutrient depletion (De Jager *et al.*, 1998a and 1998b; Drechsel & Gyiele 1999, Moukoko Ndoumbe 2001). In combination with socio-economic data, nutrient budgets can assist in identification of factors important for sustainable management of land, and can be used to develop recommendations for biophysical and socio-economic aspects of sustainability (Smyth & Dumanski, 1993; Syers & Bouma 1998; Konboon *et al.,* 2000; Lefroy *et al.,* 2000).

APPLICATION TO NATIONAL PROGRAMMES ON IMPROVING SOIL TECHNOLOGIES

The methodology developed seeks to integrate changes in land quality into economic farm accounts Its objective is to prepare accounts that will accurately reflect real sustainable income levels at farm level. The methodology focuses on measuring changes in the chemical quality of farmland. To this end, it provides tools for the measurement of nutrient inflows and outflows, and the incorporation of these measurements into physical and monetary accounts; the development of an integrated environmental and economic accounting framework at farm level; and analytical approaches and potential applications to improve natural resource and environmental policies and planning.

The farmers' involvement in the application of methodology is sought through their views while collecting the information relating to farming practices, cropping systems and economic accounting, as a part of the participatory process.

Integrating calculations on resource deterioration or restitution in the financial accounts helps to determine productivity and efficiency of farming activities according to the technologies applied. Consequently, the methodology enables the formulation of technical recommendations that integrate economic and environmental factors in a clear and simple way for use by decision makers and farmers. Such recommendations provide insights to farmers on how to improve, or at least to maintain, resource availability and capability, so making their livelihoods more sustainable.

As an important step in the development of the methodology, case studies were undertaken in Colombia, Costa Rica, Thailand and Bangladesh. These aimed at implementing, assessing and verifying the applicability, usefulness and effectiveness of the methodology. Besides directions for further improvement and implications of the outcomes for the different stakeholders, a review of the methodology has suggested several possible applications. These are briefly described below.

A framework for accounting for the contributions of the land to agricultural production

It is widely recognized that traditional farm and national accounting ignores the contribution of non-marketed inputs provided by natural capital such as land. This methodology provides a variety of physical and monetary indicators of changes in land quality and productivity, such as nutrients availability and flows, whic can help to overcome this weakness.

A tool to assess efficiency and productivity in soil resources management and farming systems

Nutrient balance indicators may provide useful insights to assess nutrient and soil fertility management with implications for farming system efficiency. Negative balances, as in the conventional cassava/maize and cacao/maize systems in Colombia, imply that the farming system is producing crops and livestock by consuming natural fertility, which may lead to declining output. On the other hand, positive nutrient balances accompanied with high nutrient losses due to erosion or leaching, as in the conventional farming systems in Costa Rica, indicate low efficiency in nutrient management with high fertilizer costs and implications for environmental pollution.

A tool for assessing feasibility of current conservation technologies

Through processing technical, socio-economic and natural resource data in an integrated manner, the methodology has proved to be useful for assessment of conservation technologies and programmes with expected impacts on natural resources and the environment. Valuing the net incremental quantity of nutrients and physical productivity makes it possible to evaluate the economic benefits of using conservation and environmentally sound practices.

A decision-support tool for land and development programmes

The methodology contributes to clear-cut projections of the positive economic and environmental effects of certain land use technologies. The successful application of the methodology to assess the impact of nutrient management suggests that the method can be used to improve feasibility appraisals in a variety of ecological circumstances.

MAKING THE INFORMATION ACCESSIBLE TO A VARIETY OF USERS

In their present state, the operational procedures and guidelines and the integrated computer workbook are quite accessible and effective. However, there is scope for further improvement and efforts to make the information more easily accessible to the stakeholders and users. During implementation of the programme, the computer workbook can be made more user-friendly through building in mechanisms for detecting data entry mistakes and a list of common mistakes and measures to avoid them.

Specific and clear guidelines should be provided on how to convert data such as fertilizer prices into nutrient prices. Conditions and circumstances under which data gaps may be filled through data transfer methods should be explained simply and in more detail. Caution to be exercised in the interpretation and use of data from laboratory analyses should be explained to the users and others involved in implementing the process.

Guidance regarding the significance and scope of application of various indicators, the potential and desirable levels of analysis and the relevant analytical paths could further enhance accessibility. A glossary should explain all technical and uncommon words used in the methodology documents. The methodology can be used to forecast the effects and impact on land and soil of alternative intervention scenarios. Specific guidelines could be provided to help carry out such simulations.

As far as possible the documents should be provided in the local language.

8. Conclusions and recommendations

A better understanding of the interrelations between environmental and socio-economic aspects is important in decision making related to soil management. Assessment of the nutrient balance is a powerful tool for the development of such an understanding and for evaluation of the sustainability of agro-ecosystems. Nutrient balance principles can be linked to socio-economic data and used to develop improved recommendations aimed at biophysical and socio-economic aspects of sustainability. Further, the nutrient balance and budget exercises have a significant educational role in farmer participatory research and participatory extension.

Integrating calculations on resource deterioration or restitution in the financial accounts helps to determine productivity and efficiency of farming activities according to the technologies applied. It also helps to understand the contribution of natural capital such as land to agriculture. A methodology seeking integration of changes in land quality into economic farm accounts has been designed by the Agricultural Management, Marketing and Finance Service of the Agricultural Support Division (AGSF), FAO and the Royal Tropical Institute (KIT), Amsterdam. The methodology facilitates preparation of accounts that will accurately reflect real sustainable income levels at farm level. It accounts for changes in the quality and fertility of cultivated land and soil as an integrated input for calculating nutrient balances and farm income. To this end, it provides for the measurement of nutrient inflows and outflows, and the incorporation of these measurements into physical and monetary accounts; the development of an integrated environmental and economic accounting framework at farm level; and analytical approaches and potential applications to improve natural-resource and environmental policies and planning. The methodology enables the formulation of technical recommendations that integrate economic and environmental factors in a clear and simple way for use by decision-makers and farmers. Such recommendations should provide insights to farmers on how to improve, or at least to maintain, resource availability and capability, so making their livelihoods more sustainable.

As an important step in the development of the methodology, case studies aimed to implement the methodology and assess and verify its applicability, usefulness and effectiveness were undertaken in Colombia, Costa Rica, Thailand and Bangladesh. The results of the case studies have shown that the methodology enables efficiency and productivity to be estimated in a simple and effective way at different management levels.

The negative nutrient balances in the conventional cassava/maize and cacao/maize systems in Colombia show that these farming systems involve reductions in natural fertility. The positive nutrient balances in the conventional farming systems in Costa Rica might be interpreted as increases in fertility and natural capital. However, these indicators should be viewed with caution because of the high erosion rate in the region. This might be affecting the efficiency of nutrient management, given the high costs of fertilizers and the failure to take pollution problems into account. The methodology proved useful in gauging the feasibility of conservationist alternatives through integrating environmental and economic aspects. From the results of these experiences, it was concluded that it is possible to evaluate the economic benefits of conservation practices by measuring the net increase in nutrients and physical productivity. It was further established that the methodology could be used to evaluate improvements in economic and environmental aspects in land-use technologies.

The Thailand case study led to the conclusion that at the farm level, integrated socio economic and environmental accounting could be a practical method to assess biophysical and socio-economic performance and sustainability. The outcomes of such analyses may be useful for decision support aimed at increased biophysical and socioeconomic sustainability of land use systems, at least in terms of improved nutrient management. The study further concluded that partial nutrient balances give a good insight into sustainability of land use; that the means of farm households to invest in nutrient balance strongly depend on their aggregate income from rice and non-farm activities; and that site- and situation-specific management by farmers leads to high variability in use of inputs, and consequently to variability in nutrient balance. Not unexpectedly, farmers tend to favour better land over marginal land. This leads to further heterogeneity on the farms and in the regions, and may lead to a mosaic landscape with patches of good agricultural land mixed with wasteland.

Considering the results of the Bangladesh case study, the participating national institutes made the following assessment about the methodology and associated guidelines. The proposed methodology is a timely and useful tool in accounting for changes in land and soil quality as measured through net nutrient depletion and accumulation; the methodology appears particularly appropriate for analysing the soil productive capacity and appropriateness of sustainable management practices; integration of soil accounts into farm, and subsequently into national accounts is a timely operation as it would help make national scientists and policy-makers fully aware of the seriousness of soil imbalances and the need to take appropriate measures for the future; and difficulties in data generation, collection and coordinated build-up of a relevant technical and farm resource management database are major constraints to the establishment of integrated economic and environmental accounting. In this context, the need arises to bridge major data gaps. Supplementary data generation, validation and documentation are needed to measure the impact on nutrient inflows and outflows of weathering of minerals, floods, irrigation, leaching and decomposition of organic matter.

Findings from the case studies showed several qualities and advantages of the methodology.

The methodology permits the estimation of actual costs for each crop, including nutrient opportunity costs:

- It introduces into the analysis of farm business assets the concept of fixed capital consumption and its replacement allowance as a condition for ensuring sustainability in land use and productivity.
- It helps ensure that natural assets are treated in the same way as produced assets.
- It is useful for tracking nutrient inflows and outflows at both farm and sub-basin level.
- It enables the identification and characterization of the sustainable income level for the farm while highlighting the variables most critical to making the system more efficient in terms of nutrient management.
- It makes it possible to develop recommendations on economically and environmentally appropriate fertilizer use and projections concerning the economic and environmental sustainability of the relevant agricultural production system.
- It provides a means of evaluating the economic benefits of conservationist practices and soil rehabilitation programmes.
- It can be effectively applied in various agro-ecological zones.

The methodology has a wide range of applicability. Some of the possible applications include: a framework for accounting the land contributions to agriculture production; a tool to assess efficiency and productivity in soil resources management and farming systems; a tool for assessing feasibility of current conservation technologies; a decision-support tool for land development programmes.

RECOMMENDATIONS

The outputs from the methodology can be interpreted more fully if the data provided by conventional accounts on such production systems are available.

A multidisciplinary effort is needed to analyse available data and collect information from primary sources.

The farmers' involvement in the application of methodology is sought through their views while collecting the information relating to farming practices, cropping systems and economic accounting, as a part of the participatory process. There is further scope for incorporation and integration of various elements the PLAR process in the methodology.

During implementation of the programme, the computer workbook should be made more user-friendly through provision of detailed user guides, tutorials for the workbook encompassing basic and comprehensive instructions, built-in mechanisms for detecting data entry mistakes, and a list of common mistakes and measures to avoid them.

Further, specific and clear guidelines could be provided on how to convert data such as fertilizer prices into nutrient prices. Conditions and circumstances under which data gaps may be filled through data transfer methods should be explained more clearly. Caution to be exercised in the interpretation and use of data from laboratory analyses should be explained to users and others involved in implementing the process.

Guidance regarding the significance and scope of application of various indicators, the potential and desirable levels of analysis and the relevant analytical paths should further enhance accessibility. A glossary should explain technical and uncommon words in the methodology documents. The methodology can be used to forecast the effects and impact on land and soil of alternative intervention scenarios. Specific guidelines should be provided to help carry out such simulations.

In short, valuing land quality changes in conventional farm accounts offers a unique opportunity to assess the sustainable income at the farm level and enrich the measurement of farming system efficiency. Illustrating the value of land assets in the quantification of outcomes may help to raise decision makers' awareness of the value of environmental assets usually ignored in financial accounting.

Annex 1

Participatory learning and action research

Participative learning and action research (PLAR) is a farmer learning process facilitated by change agents. The focus is on self-discovery and experiential learning by farmers. PLAR emphasises individual and communicative learning and is characterized by procedures, steps and methodological tools. A PLAR process applied to soil fertility management aspects is marked by procedures comprising several steps including a varying number of methodological tools. Several of the methodological tools draw on the principles of participatory rural appraisal, rapid appraisal of agricultural knowledge systems (RAAKS), wealth ranking and resource mapping. The process incorporates adaptations to typically cover soil fertility aspects relating to site-specific conditions (Defoer & Place 2000; Defoer 2002).

PLAR is based on four key principles: a community approach, addressing diversity, dealing with representative test farmers, and building on feedback.

A COMMUNITY APPROACH

The farmer community, generally a village or grouping of villages composed of individual farming families, is the first level of intervention. This supposes that the village forms a unity with a certain leadership and social cohesion. PLAR aims at involving the whole village population. Community meetings are organized at the start and end of each of the PLAR phases in order to achieve this objective.

ADDRESSING DIVERSITY

Diversity is an intrinsic characteristic of farming and a determinant of soil fertility management strategies. Farmers analyse the diversity within the community using a range of methodological tools. Depending on the requirements, different types of diversity analyses can be done: analysis of the village land use system, analysis of management strategies or analysis of community organisational and kinship structures.

The outcomes of the diversity analyses form the basis to select 'test' farmers, representing the diversity of soil fertility management strategies that are found at the village level.

DEALING WITH REPRESENTATIVE TEST FARMERS

Test farmers form a farmer committee, which acts as an intermediate between the facilitators and the rest of the villagers. The existing situation is analysed in depth at the level of the farm households and of the test farmers (the farmer committee). Similarly, in-depth planning and evaluation, and experimentation to evaluate alternative management practices and potential solutions are done by the test farmers.

BUILDING ON FEEDBACK

Findings obtained with the representative test farmers are fed back during plenary sessions with groups of farmers or at the village community level.

Planning and design of soil fertility management strategies

The PLAR process consists of four phases (Figure A1-1). PLAR starts with an initial diagnosis (Phase 1), and proceeds with a cycle of planning (Phase 2), implementation and experimentation (Phase 3) and evaluation (Phase 4). The cycle is repeated on a crop seasonal basis and forms the heart of the long-term engagement between farmers and the field team. Each of the phases is characterized by a procedure comprising several steps including a varying number of methodological tools (Defoer 2002).

The initial diagnostic phase involves investigations with a series of steps at the level of the village community, farmers' group and farm household (Table A1-1).

Resource flow mapping is an important PLAR learning tool. It consists of farmers making a simplified picture of their farm system and its resource flow pattern, including elements that are crucial in soil fertility management. In case of the initial resource flow map, the picture presents an overview of how the farmer actually manages the fertility of his lands, and depicts interactions (or absence of interaction) between farm elements and elements outside the farm (Figure A1-2).

In discussions farmers and team members analyse resource use, criteria for soil fertility management, crop-livestock integration, resource losses, dependency on external inputs, changes that occurred during recent years, possible improvements and preferred strategies with particular reference to increased organic recycling, controlling resource losses, and rationalization of external input use.

With the resource flow map as a basis, a planning map can be made. The planning map represents a picture of the farmer's plans for the coming season, indicating new farm elements and techniques to be tried out, the way resources will be managed and where on the farm experimentation will take place. While planning, interventions are sought at the level of village, community or group of farmers and of the farm household (Table A1-2).

FIGURE A1-1
The participatory learning and action research process (Defoer 2002)

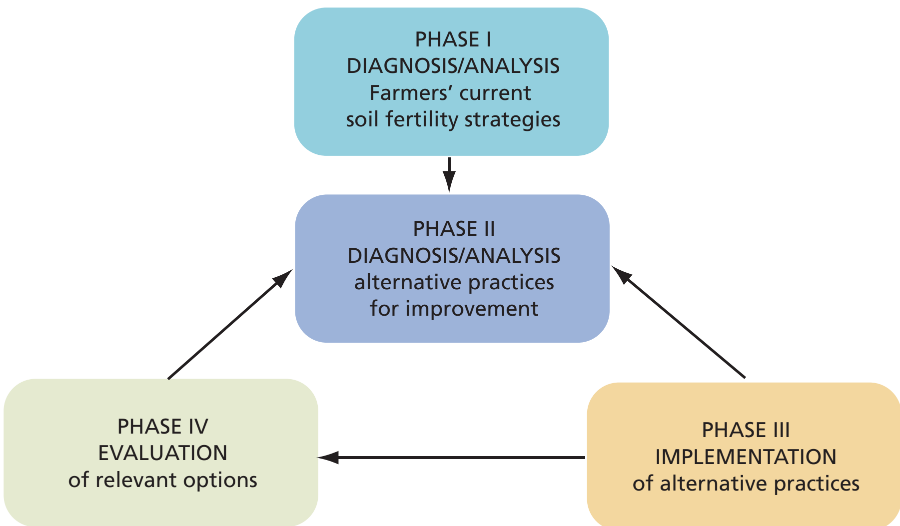


TABLE A1-1

Steps in the diagnostic phase

Step 1. Introductory community meeting (community level)
- To introduce the field team and the village community
- To agree on a framework for intervention, and on objectives and procedures of the fieldwork

Step 2. Analysis of the village land use systems (group level)
- To identify how farmers use and manage the community's natural resources: emphasis on diversity
- To make a village territory map: to depict settlement patterns, land units, soil types, land use, land degradation and areas where communal action can be implemented
- To make a village territory transect walk: to elaborate on information obtained from the territory map.

Step 3. Analysis of management diversity (group level)
- To investigate differences in the way farmers cope with soil fertility problems and to assess farmers' views on what constitutes proper soil fertility management practices and on factors contributing to a household's capability to manage soil fertility.
- To make a classification of all farms of the village
- To analyse constraints and potentials for various classes of farms and to subsequently identify options for improvements

Step 4. Diagram of village organizations (group level)
- To analyse the diversity of farmers' information and communication networks; farmers' social relations; and the types, sources and uses of information.

Step 5. Selection of the farmers (group level)
- To select 'test' farmers from each farm class, taking account of the prevailing landscape diversity, kinship structure of the village, and farmers' ability to communicate, try out new techniques and exchange information with colleagues; list farmers from the core groups during the subsequent phases of the process approach.

Step 6. Formation of a farmer committee (group level)
- To form a farmer committee composed of the selected test farmers; to form a bridge between the team and the rest of the villagers

Step 7. Farm resource flow map (RFM) (household level)
- To visualize and analyse in-depth the test farmers' soil fertility management practices.
- To identify possibilities for improved soil fertility management per farm class.

Step 8. Conducting a community meeting (community level)
- To present findings of the analyses.
- To motivate farmers to take action.

Source: Defoer 2002

TABLE A1-2

Steps in the planning phase

Step 1. Farmers' workshop (community level)
- To exchange viewpoints between farmers and team on how to treat the problems and constraints diagnosed.
- To review options for improved soil fertility management.
- To assist farmers to set priorities and make a preliminary choice of activities they want to carry out.

Step 2. Farmer exchange visit (group level)
- To allow farmers to observe and discuss the effects of the new techniques discussed during the farmers' workshop.

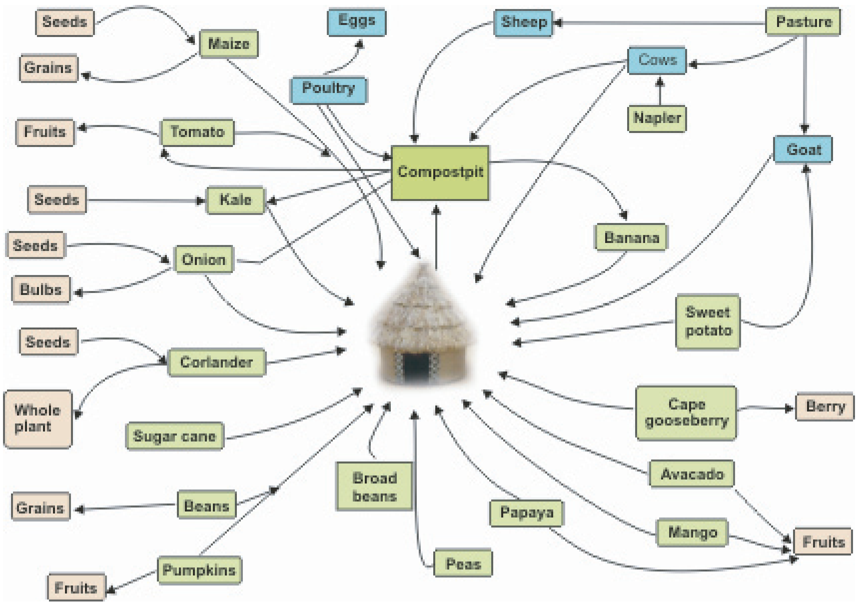
Step 3. Planning map (household level)
- To visualize plans for the next season, individually by the test farmers.

Step 4. Committee's action plan (community level)
- To visualize plans in the form of a matrix listing the type of actions to be carried out and providing details for each activity: date, venue, target groups, number of farmers involved, team involvement and materials required.

Step 5. Concluding planning meeting (community level)
- To present the plans for the coming season to all villagers.
- To motivate all farmers to take action.
- To discuss implications of executing the planned changes.

Source: Defoer 2002

FIGURE A1-2
Example of a resource flow map



Based on Budelman and Defoer 2000

Implementing and evaluating soil fertility management strategies

Implementation and evaluation follow the planning stage. Steps involved in the implementation phase are listed in Table A1-3.

The evaluation phase includes interventions at the same two levels as the earlier phases. Steps in the evaluation process are listed in Table A1-4.

After the introductory meeting, test farmers individually evaluate their planned activities, using their planning map, by indicating the activities they actually implemented, thereby changing their planning map into a map of implemented activities. A transformation of the planning map into implemented activities map could present a picture of the farmer's achievement as compared to what had been planned. By comparing, the reasons that explain discrepancies can be discussed.

An analytical framework for evaluation may be used. Through the analytical framework, the information gathered in a participatory way is turned into quantitative data. The farm-based resource flow maps, made on a yearly basis by test farmers, are used for this purpose. The information from the resource flow maps is first transferred onto monitoring forms, which are subsequently fed into a computerized data base. The data base captures the different farm components and resource flows. The files of the data base can be linked and aggregated in order to estimate flows for the farm as unit of analysis.

Two types of indicators can be used to evaluate the impact of PLAR: management performance indicators or nutrient flows and nutrient balances (Defoer et al. 1998, 2000; Defoer & Place 2000). Management performance indicators are selected on the basis of farmers' criteria for good soil fertility management, identified during farmers' analysis of farm diversity. For the management performance indicators, averages are calculated for all test farms and per farm class, as determined during farmers' diversity analysis.

TABLE A1-3
Steps in the implementation phase

Step 1. Farmer training sessions (group level)
- To cover farmers' knowledge gaps identified during the diagnostic phase.

Step 2. Experiment design meeting (group level)
- To assist farmers in formulating the objectives of their experiments and making an appropriate experimental design.
- To agree on procedures for experimental design and for monitoring the experiments.

Step 3. Demonstration of layout (group level)
- To train farmers in how to carry out the experiment.

Step 4. Monitoring of experiments (household level)
- To enable farmers to assess the performance of the technique and identify what can be learned from the experiment.

Step 5. Field visit (group level)
- To discuss among experimenting farmers and exchange insights.
- To invite non-experimenting farmers to join and to start a similar activity.

Step 6. Farmer-to-farmer training (group level)
- To organize training sessions by test farmers who form small informal groups with their neighbours to exchange the newly acquired knowledge with them.

Step 7. Managing experiment data (group level)
- To summarize information collected in the course of the experiments.
- To discuss outcomes of the experiments with the test farmers.

Step 8. Field day (community level)
- To show to farmers of neighbouring villages what has been learned and the changes that have been undertaken.
- To interest neighbouring villages to set up a similar programme of action.

Source: Defoer 2002

TABLE A1-4
Steps in the evaluation phase

Step 1. Introductory evaluation meeting (community level)
- To joitly decide upon the objectives and procedure of the evaluation phase.

Step 2. Map of implemented activities (household level)
- To evaluate individually planned activities, using the planning map.
- To compare activities planned and really executed.
- To compare with the resource flow map and assess improvements in management practices.

Step 3. Evaluation of the action plan and concluding evaluation meeting (group or community level)
- To present findings and actions to all interested villagers.
- To assess differences between planning and achievement.
- To decide on a period to start a following planning-implementation-evaluation cycle.

Source: Defoer 2002

Comparison and establishing a measure of importance of the resource flows to the farming system requires their transformation into nutrient flows. The annual values of all resource flows are first converted into N, P and K values. Then, farm-level data are divided by the total cultivated area per farm to obtain figures per hectare. Nutrient balances can then be made at farm and field levels. Nutrient flow analysis shows the linkages among the farm elements and the inflows and outflows of the system. The analysis also allows assessing the effect of the changes in practices farmers have made and results obtained by different groups of farmers implementing PLAR.

Until now, the studies implemented using PLAR have been using partial nutrient balances, ignoring natural nutrient inflows through weathering and fallow, nutrient losses through erosion and losses from fertilizer and manure. Presently the method gives no indication on the real nutrient depletion under farming. The partial budgets are used for discussion with farmers and for comparing different practices, but valuation of changes in the natural capital of farmers is still to be developed.

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