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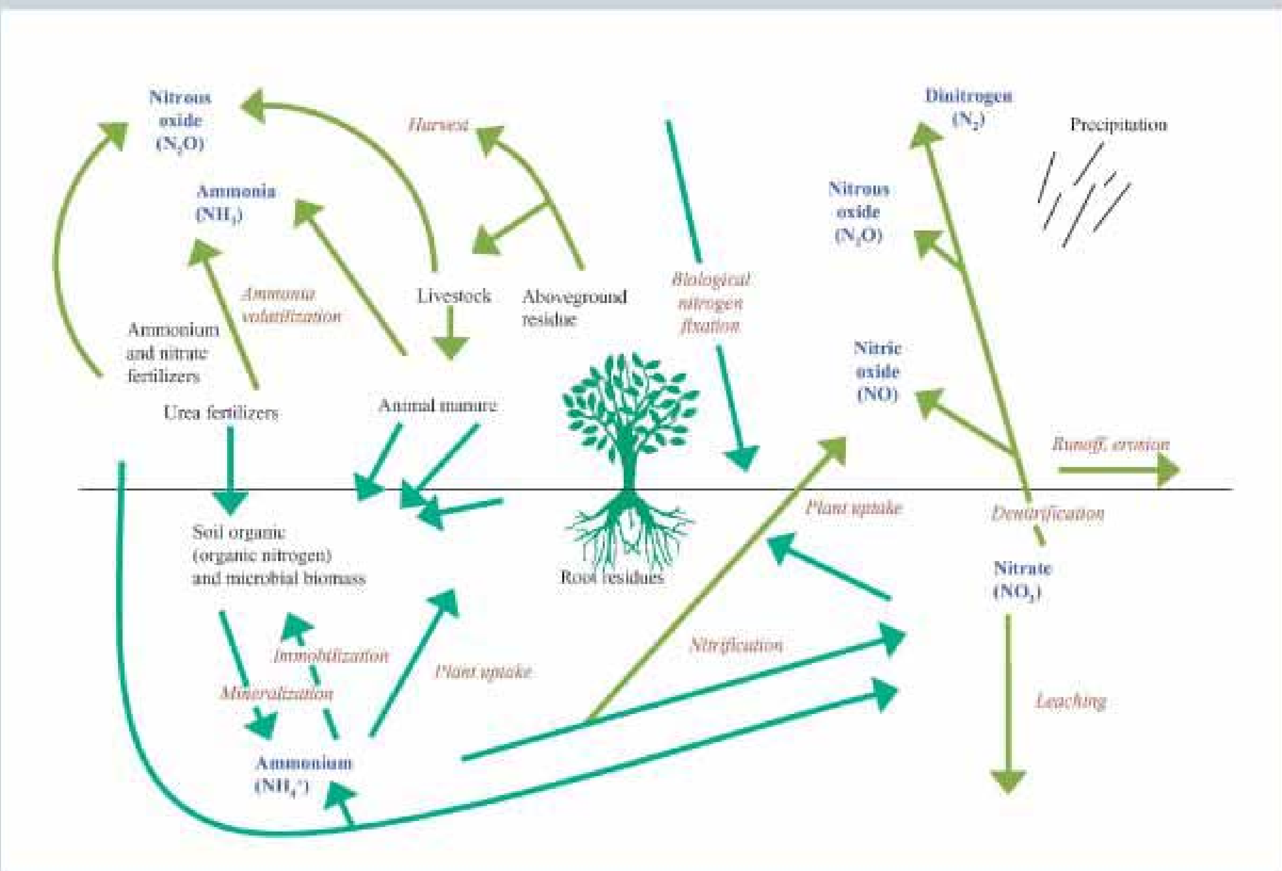

Assessment of soil nutrient balance

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Preface

Agricultural intensification without adequate restoration of soil fertility may threaten the sustainability of agriculture. Quantitative estimation of plant nutrient depletion from soils is useful for comprehending the state of soil degradation and for devising corrective measures. Nutrient-balance exercises serve as instruments to provide indicators of the sustainability of agricultural systems.

Nutrient-balance studies have used a variety of approaches and methods for different situations. However, the information has remained scattered in several publications. In order to address this issue, the Land and Water Development Division (AGL) of FAO organized an electronic conference on 'Assessment of soil nutrient depletion and requirements - approach and methodology' from September 2002 to July 2003. The electronic conference enabled institutions, agencies and scientists to share information and exchange ideas, views and experiences on the subject. A background document reviewing known approaches and methodologies was made available to the participants as a starting point for discussion.

This publication is the outcome of an amalgamation of the technical contents of the background paper, the inputs of the electronic conference, and further reinforcement through the latest literature and analysis. The publication presents a state-of-the-art overview of nutrient-balance studies. It brings out the evolution of the various approaches and methodologies, provides for comparisons among them, and highlights the improvements made and the issues that are still to be addressed. It categorizes case studies into macrolevel, mesolevel and microlevel classes. The macrolevel is used for national, continental and global farming-system levels. The mesolevel coincides with the level of the province, district and agro-ecological zone. The microlevel is largely defined as the farm or village level. For each case, the study explains the methodological approaches, the elements of the nutrient balance, and the calculation of the nutrient flows. Furthermore, it also discusses knowledge gaps and caveats that warrant attention.

The intention is for this publication to help bridge the scientific knowledge gap and to provide updated information on nutrient-balance approaches and methodologies to the scientific community, higher level extension workers, decision-makers, non-governmental organizations and other stakeholders concerned with agricultural development.

Acknowlegements

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Executive summary

Soil nutrient-balance exercises based on static modelling systems and linear upscaling are devoid of the dynamics and the interacting processes involved. Methodological estimations are fraught with problems such as limited data availability at spatial scales, scale-specific spatial variation of nutrient-balance input data, non-linearity in upscaling, and lack of reliable upscaling techniques. Extrapolating present balances into the future and ensuring their validity for the future presents practical problems. There is a need for a more simple and reliable model/approach that is readily adaptable to various situations. In spite of various limitations, nutrient-balance assessments do delineate the consequences of farming for soil fertility. Of further relevance is their emergence as a reliable tool for devising time-scale soil fertility interventions based on a sound policy framework.

A recently concluded FAO-commissioned project, 'Scaling soil nutrient balances', and scientific interactions (FAO electronic conference, September 2002 – July 2003) have thrown further light on the critical issues concerning nutrient-balance assessment approaches. They may also help bridge methodological gaps. Further methodological refinements are feasible through making them more spatially explicit (accounting for spatial variation of soils and climate) and through improving the procedures for calculating nutrient flows and quantifying soil nutrient stocks. The introduction of mesolevel studies adds value to the existing national- and farm-level approaches. The mesolevel offers a suitable entry point for policy interventions.

Although macrolevel uncertainties need to be minimized and validations improved, it may not be possible to validate all the nutrient flows; one can focus on validating the specific flows regarded as most important. A participatory approach for the development and validation of locally specific packages needs to be promoted. Larger pools and volumes of data may facilitate refinement of the models and make them more scalable.

Intensive field checks can in part solve problems relating to data quality, map interpretation, resolution differences and groundtruthing at the macrolevel. New techniques such as reflectance spectroscopy can inject elements of precision, pace and ease into the assessment of soil properties and nutrient stocks. Classified satellite images and digital elevation models (DEMs) can bring significant improvements in mesolevel nutrient-balance studies. Stratification in sampling methods and the use of GIS for upscaling would help improve mesolevel assessments.

Presentation of the assessment outcomes in terms of yield loss or monetary values enables policy-makers to understand the issues more readily. Programmes to assist national governments in enhancing their socio-economic and policy environment for soil improvement (with the aim of promoting productive and sustainable agriculture) would be a prudent and desirable proposition.

Acronyms

AEZ	Agro-ecological zone
B	Boron
BNF	Biological nitrogen fixation
Ca	Calcium
CEC	Cation exchange capacity
CMDT	Compagnie Malienne pour le Développement des Textiles
DEM	Digital elevation model
EUROSTAT	Statistical office of the European Communities
FFS	Farmer field school
FSU	Farm section unit
GIS	Geographic information system
IAA	Integrated agriculture-aquaculture
ICRAF	International Center for Research in Agroforestry
IFDC	International Fertilizer Development Center
ILRI	International Livestock Research Institute
INM	Integrated nutrient management
ISRIC	International Soil Reference and Information Centre
K	Potassium
LAPSUS	LandscApe ProcesS modelling at mUltidimensions and Scales
LUS	Land use system
LUT	Land use type
LWC	Land/water classes
Mg	Magnesium
Mo	Molybdenum
N	Nitrogen
NUTMON	Nutrient monitoring
OECD	Organisation for Economic Co-operation and Development
P	Phosphorus
PET	Potential evapotranspiration
PLAR	Participatory learning and action research
PPU	Primary production unit
PRA	Participatory rural appraisal
QUEFTS	Quantitative Evaluation of the Fertility of Tropical Soils
RU	Redistribution unit
S	Sulphur
SPU	Secondary production unit
SSA	Sub-Saharan Africa
USLE	Universal Soil Loss Equation
WISE	World Inventory of Soil Emission potentials database
Zn	Zinc

Chapter 1
Introduction

Continuous cropping without adequate restorative practices may endanger the sustainability of agriculture. Nutrient depletion is a major form of soil degradation. A quantitative knowledge on the depletion of plant nutrients from soils helps to understand the state of soil degradation and may be helpful in devising nutrient management strategies. Nutrient-balance exercises may serve as instruments to provide indicators for the sustainability of agricultural systems. Nutrient-budget and nutrient-balance approaches have been applied widely in recent years. Studies have been undertaken at a variety of levels: plot, farm, regional, national and continental. Widespread occurrence of nutrient mining and soil fertility decline has been reported.

Most nutrient-balance studies provide rapid findings, based on a short time-frame exercise, and necessarily depend on a number of assumptions relating to system dynamics. However, questions remain concerning the validity of such assumptions, their reliability, and their capability to provide insight into dynamic processes and lend support for extrapolation. Also pertinent is the issue as to which new approaches/directions, investigations and extra efforts are required and feasible in order to enhance the validity of the assumptions and findings. Questions have been raised as to whether nutrient budgets provide the information required for understanding the status and dynamics of soil fertility across farming systems and whether such analysis may provide reliable direction and support to policy formulation on soil fertility management (Scoones and Toulmin, 1998).

Spatial and temporal context

Spatial and temporal variations in nutrient flows and budget estimations are important. For assessment purposes, a farm is usually considered as a unit even though farms comprise different soil-type entities and management regimes. Landscapes are often characterized by their diversity in terms of physical attributes and management. Contrasting soils, slopes, drainage patterns and crop husbandry situations are encountered in individual watersheds. Diversity at village levels is also evident. While field budgets could be negative, mainly because of crop harvest removals, nutrient budgets may turn positive at village level because of reasons such as manure imports. In agropastoral settings, the relationship between crop and rangeland becomes more important. Attempts to model such systems are fraught with problems and complexities especially in the context of assumptions about variables.

Temporal dynamics is another major factor with a bearing on nutrient-balance outcomes. For example, temporal variations in livestock numbers and manure production on account of migration or similar developments may lead to a significant impact on various nutrient flows, including inputs through fertilizers and manures, as well as the outflows.

In spite of such spatial and temporal dimensions, most studies opt for 'quick-find' exercises based on averages, which may have little relevance to the real picture. Thus, sampling becomes a crucial factor, and one beset with problems for nutrient-budget exercises. In addition to soil management factors, identification of the major land types, landscapes and their variability is crucial to a reliable sampling procedure. A simple summing-up of areas covered by major soil types may not provide the attributes of the diversity that exists in the farming systems.

System flows and estimations

Identification of the key inputs and outputs in various subcomponents of a bounded system is the initial step in most nutrient-budget exercises. The system boundary, its subcomponents and the various nutrient inputs and outputs are defined.

The next step is the estimation of nutrient flows either through direct measurement or through literature estimates based on standard functions. Where data are not available for a particular scale, they are extrapolated from other scales. Nutrient-budget analyses involve accounting exercises, whereby balances are calculated through summing totals for each of the nutrients identified for study.

Assumptions – their validity and reliability margins

Nutrient-budget and nutrient-balance models have to rely on a series of assumptions in order to deal with complex nutrient systems. Many nutrient-budgeting exercises treat soil-dynamics processes as a 'black box'. The basic data for nutrient inputs and outputs are usually selected from literature and production statistics. Data from literature pertain to various sites, but may not necessarily be representative for the selected area. Some studies base their calculations on secondary data derived from certain assumptions. The data sources used for such analyses have different confidence limits attached to them. Where resource flows are translated into nutrient contents, uncertainties about data estimates also arise owing to variability in estimation procedures.

The types of input and output data that are relatively easy to measure include flows of materials, such as fertilizer, manure, crop residues and harvested grains. Several of the 'environmental' variables contributing to nutrient-balance calculations have to be estimated from secondary literature. Similarly, values for the export of nutrients in the harvested product are usually derived from secondary data relating to yields and nutrient contents in the harvested parts. Plant species reveal substantial variations in nutrient uptake. These depend on a number of factors such as climate, soil properties and farmers' crop management. Export of nutrients in crop residues varies depending on residue management by the farmer, which differs greatly between and within countries. A limited number of systematic studies have examined the leaching of nitrogen (N) and potassium (K). Leaching losses have been estimated through multiple regression. Here again, there is scope for approximation and errors. Gaseous losses refer to N and may comprise denitrification and volatilization. There are few reliable data on denitrification and volatilization for the various agro-soil-climate situations. Estimates have been made using variables and multiple regressions. Processes such as erosion account for some of the important exports of soil nutrients. Substituting transfer equations from other studies sometimes leads to a wide range of results.

For data capturing at field level, one may opt for direct measurement of certain flows. However, at higher system levels, it will not be possible to measure each nutrient flow. Although primary point data may exist, calculations are required for upscaling. Where primary data are lacking, expert judgement or literature data from other geographical areas provide only 'best guesses'.

Issues of quantification and uncertainty surround many of the nutrient transfers. The methodologies for actual field measurements of nutrient stocks are often based on nutrients in a given soil depth increment or on the concentration of nutrients in a given depth sample. The inaccuracies of the methods may result in mis-assessments. Exact determination of different soil nutrient pools is difficult because of the complex, dynamic and stochastic nature of nutrient-transformation processes in the soil system. Changes in soil nutrient stocks over time can be measured in order to form an idea about the extent of nutrient mining. However, many soil test methods do not readily reveal nutrient mining because the 'available' fraction extracted is buffered well by supply from other nutrient pools, as is often seen for K. Data availability only allows for a rough estimation of rates of changes in soil nutrient stocks. It does not permit long-term forecasts of soil nutrient stocks. Prognoses for the effect of soil nutrient depletion on future agricultural production are even more difficult to establish.

Upscaling and its validity

Problems arise when the scale is enlarged further to a district, national or continental scale. The aggregation of nutrient balances at field level leads to farm balances. The increasing complexity of the farm system and its architecture negatively affects the reliability of nutrient-balance calculations. Various parameters introduce elements of uncertainty into the overall nutrient balance.

The largest unit for which soil nutrient balances can be quantified is the field. Larger spatial scales can only be dealt with through generalization and aggregations. Land use systems in a region are generalized into a typology with a known or unknown variation. Aggregations then describe how the generalized, larger 'uniform' units are added together to yield one overall soil nutrient balance for the region. Aggregation is a delicate issue as the balance itself is made up of several parameters that are in some cases outcomes of regression analysis on more basic parameters. Model validation becomes difficult because of the lack of independent data sets that meet all the input requirements.

Socio-economic factors and their role in nutrient balances

Much of the soil nutrient debate ignores the role that farmers play in shaping the processes of environmental change. However, despite broadly similar access to resources and opportunities, marked differences often exist within a single setting in which soil fertility is handled by different farmers. Among different farmers and between areas, the relative value of land, labour and capital endowments over time may have important implications for the form and efficiency of any farm-level nutrient cycle.

Statements on soil fertility decline must refer to the relevant context. The orientation of studies towards a targeted approach to soil fertility intervention that distinguishes between farm component, agro-ecological zone (AEZ) and socio-economic groups is an appropriate approach. Non-consideration of socio-economic aspects in nutrient budget and balance studies may lead to the exclusion of many relevant factors.

Although plausible solutions may be elusive, soil nutrient-balance studies do delineate the consequences of farming for soil fertility. What is further required, and possibly more relevant, is a time-scale plan for external interventions based on a sound policy framework; this in addition to a more simple and reliable model/approach that is readily adaptable to various situations.

Chapter 2 presents a state-of-the-art overview of nutrient-balance studies at different scale levels focused on nutrient depletion. The cases are divided into macrolevel, mesolevel and microlevel scales and they are in chronological order. The scale levels are not fixed, but provide an indication of the order of magnitude. The macrolevel is used for national, continental and global farming-system level. The mesolevel coincides with the province/district/AEZ level. It can also be defined as an agro-economic entity, e.g. cotton-based or dairy-based farming systems. Finally, the microlevel is defined as the farm or village level, but it can be extended to nutrient management group or gender.

This report does not attempt to list all the nutrient-balance studies from over the years. The selection of the cases is based on the different approaches of nutrient-balance calculations and on their innovative character. For the microlevel, several cases describe a specific niche management where some fields/crops/landscape units are cherished at the expense of others. All the selected cases have been published in international journals or books. Various books and journals provide further information on nutrient balance and soil fertility related research (e.g. Smaling, 1998; Scoones and Toulmin, 1999; Smaling, Oenema and Fresco, 1999; Vanlauwe *et al.*, 2002).