Practice makes perfect:

Participatory innovation in soil fertility management to improve rural livelihoods in East Africa

André de Jager

Practice makes perfect:

Participatory innovation in soil fertility management to improve rural livelihoods in East Africa

Promotoren: Prof. Dr. Ir. H. van Keulen
Hoogleraar bij de Leerstoelgroep Plantaardige Productiesystemen
Wageningen Universiteit

Prof. Dr. K.E. Giller
Hoogleraar Plantaardige Productiesystemen
Wageningen Universiteit

Prof. Dr. Ir. C. Leeuwis
Hoogleraar Communicatie- en Innovatiestudies
Wageningen Universiteit

Promotiecommissie: Dr. A. Bationo (Tropical Soil Biology and Fertility Institute of CIAT, Nairobi, Kenya)
Prof. Dr. Ir. L.O. Fresco (Universiteit van Amsterdam)
Prof. Dr. M. Mulder (Wageningen Universiteit)
Prof. Dr. Ir. O. Oenema (Wageningen Universiteit)

Dit onderzoek is uitgevoerd binnen de onderzoekschool: Production Ecology and Resource Conservation

Practice makes perfect:

Participatory innovation in soil fertility management to improve rural livelihoods in East Africa

André de Jager

Proefschrift

Ter verkrijging van de graad van doctor
op gezag van de rector magnificus
van Wageningen Universiteit,
Prof. Dr. M.J. Kropff
in het openbaar te verdedigen
op vrijdag 30 november 2007
des namiddags te 16.00 in de Aula

André de Jager (2007)

Practice makes perfect: participatory innovation in soil fertility management to improve rural livelihood in East Africa.

PhD Thesis, Wageningen University, Wageningen, The Netherlands
With summaries in English and Dutch

ISBN: 978-90-8504-842-8

Abstract

Maintaining and improving soil fertility is crucial for Africa to attain the Millennium Development Goals. Fertile soil and balanced soil nutrient management are major foundations for sustainable food production, contribute to a sound management of natural resources and assist in controlling environmental degradation such as erosion, loss of biodiversity, pollution of water sources and acidification. This thesis describes the development of an inter-disciplinary diagnostic tool to assess impacts of farm management practices on nutrient balances and the use of the tool in participative research and innovation approaches in East Africa over a ten-year period from 1995 to 2005.

The structured conceptual framework and related NUTMON approach facilitate a comprehensive description and analysis of management practices in complex smallholder farming systems. The approach has been successfully applied in a variety of projects addressing soil fertility degradation in Africa and Asia. A wide audience from both the research and development communities have been exposed to the approach. The integration of biophysical, financial and livelihood aspects in the analyses proved essential to assist effective decision making by farm households. The quantitative analysis based on farmers' own data and observations, complements other participative tools and contributed to learning and innovation processes within households.

The various projects which implemented the approach showed that negative soil nutrient balances and high incidence of poverty prevail in most of the farming systems in East Africa. However, huge variations between geographical areas and individual farms were observed. Farmers often successfully integrated technical innovations in existing farm management systems, whereby combinations of application of organic manure and fertilizers appeared to be the most effective strategy.

The research has shown that, once smallholders are equipped with knowledge and the capacity to learn, are empowered in organizations and connected to markets and the private sector, they can substantially improve their rural livelihoods. Therefore a focus on participatory experiential learning approaches and farmer organizations that result in new arrangements in innovation systems needs to be mainstreamed in rural development projects. Experiences show that the sustainability of group learning processes increases considerably when the groups engage successfully in commercial activities at the same time.

Innovations in soil fertility management were most successful and had the greatest impact on livelihoods in areas with both high agricultural potential and access to large urban markets. Investments in soil management or other technologies can be realised more easily by smallholders when they have opportunities to generate cash through commercial sales and value-addition, or when they have access to non-farm income. In more marginal areas most investments in inputs and technologies were financially unattractive or risky. In these areas priority needs be given to creating a more conducive environment for smallholders to do business and explore alternatives to food crop production.

Keywords: soil nutrient balances, soil fertility degradation, East Africa, participatory innovation, experiential learning, farmer field schools, smallholder agriculture

Preface and acknowledgement

In March 1994, Eric Smaling contacted the Agricultural Economics Research Institute (LEI) requesting the participation of an economist in an inter-disciplinary team to work on a pilot project 'Monitoring nutrient transfers to quantify the productivity and sustainability of agro-ecosystems' to be implemented in 4 districts in Kenya. Immediately I was triggered by the topic and succeeded to convince the management that, despite the limited funds available, this was an excellent opportunity for LEI to participate in a major Wageningen-broad international research initiative. At that time I had no idea which major impacts this step would have on my future career.

The pilot project marked the start of my involvement in applied research in soil fertility management in Africa for a period of more than 10 years. In the initial phase Eric Smaling was my major source of inspiration. We shared a passion for working in Africa. He inspired me and many colleagues to join forces and address soil fertility problems in a holistic way. He managed to convince me of the importance of publishing research results in scientific journals and also gave the final push to bundle these articles in a PhD thesis. Later I joined Eric in his efforts to ensure that international development-oriented research remained one the priority areas of DLO. Eric, thanks for your support and friendship.

In the course of the years a dynamic and active interdisciplinary group of researchers emerged, which managed to acquire and implement a number of long-term inter-disciplinary international projects addressing this topic. This team consisting of Rik van den Bosch, Siebe van Wijk, Joost Vlaming, Gerdien Meijerink and myself, worked hard to translate the overall concepts into workable models and operational software. During missions many nightly hours were spent to deal with all the nitty-gritty of complex farming systems, even more complex data sets and software bugs. But work was always alternated with sufficient social activities and we shared many happy after-work hours with the team and with Kenyan and Ugandan colleagues. I thank you all for the friendship and cooperation during this period, which I remember as one of the most enjoyable of my working life. Without your inputs this thesis would never have been realised.

Special gratitude goes to the late Stephen Nandwa of the Kenyan Agricultural Research Institute (KARI). He was one of the most energetic supporters of the development of the NUTMON model and facilitated a wide use of the approach in East Africa. He facilitated many of the projects implemented in Kenya and became a good friend of all members of the NUTMON team.

Most of my time spent in rural Kenya was jointly with Davies Onduru (ETC East Africa). We collected data, facilitated farmers meetings, discussed on-farm experiments, facilitated Farmers Field Schools and jointly wrote reports and papers for the last 10 years. Davies thank you very much for your conscious and hard work, your support and input in many of the projects and papers forming the basis of this thesis. Also a special thanks to Fred Muchena (Deputy Director ETC East Africa) and Mateete Bekunda (Dean Faculty of Agriculture at Makerere University Kampala) for your support, critical discussions and friendship while being in Kenya and Uganda.

Herman van Keulen, my promoter, was actively involved in the development and implementation of the NUTMON model. In one of the projects, NUTSAL, we regularly conducted field work in Kenya and shared the usual moments of frustrations interchanged with moments of success. Herman, thanks for the always constructive critical discussions and very detailed comments on draft versions of the various papers. Also a special thanks to Ken Giller en Cees Leeuwis, my other promotors who gave valuable feedback, comments and overall directions during the last phase of writing my thesis. A special thanks goes to Ken, who continued to motivate me to finalise this endeavour by continuously telling me 'you are almost there'.

I wish to thank Jetse Stoorvogel for his critical remarks on some of the drafts and his efforts of linking the NUTMON tool and data to the trade-off approach aiming at improved communication of research results to policy makers. Also thanks to Wietse Dol en Foppe Bouma of LEI for their support in the software development.

All the work presented in this thesis was done in close collaboration with researchers, extension and NGO-staff in Kenya and Uganda. Through your dedication in sometimes difficult circumstances, working with preliminary versions of the model, you played a crucial role in laying the foundations of this approach. Special thanks to you all:

- From Kenya Agricultural Research Institute (KARI): Louis Gachimbi, J.N. Gitari, I. Kariuki, N.G. Gachini, E. Gitonga Thuranira, A.M. Karuku, J. Itabari, F. Mainah, F.M. Matiri, M. Odendo, J.M. Wanyama;
- From Environmental Alert, Uganda: Charles Walaga, Fred Kafeero, Beatrice Nankacwa and Joshua Zake;
- From Makerere University: Peter Ebanyat.

During the years of field work, I had the privilege to visit many smallholder farmers in various rural areas of the two countries for a period of time, jointly walking through their farms and discussing challenges and opportunities. In this period I developed a high appreciation for the entrepreneurship and creativity of male and female farmers trying to make a living for their families in often hard and unpredictable circumstances. I really thank you for the always warm welcome, the insight you provided into the beauties and challenges of rural life in East Africa and the active participation and collaboration in the project activities. I sincerely hope that you have reaped some benefits from the project activities and achieved substantial improvements in your livelihood.

The Royal Swedish Academy of Sciences, Elsevier Limited and Earthscan are thanked for their permission to reproduce previously published papers in this thesis. I thank the management of LEI for making time available, allowing me to walk the last mile of this project.

I would like to thank my parents who supported me during my initial steps towards a university education and in all my activities which followed thereafter. The projects, forming the base of this thesis, involved frequent travelling and being away from home. I wish to thank Jacqueline, Ilse and Arno for their patience during these too frequent periods of absence. Your continued love has provided me with a comforting home to return to after every trip. This home formed the foundation for the work in this thesis.

Table of contents

Part 1 Introduction

Setting the stage

Maintaining and improving soil fertility is crucial for Africa to attain the Millennium Development Goals (www.unmillenniumproject.org), specially contributing to 'Eradicating extreme poverty and hunger (MDG 1)' and 'Ensuring environmental sustainability (MDG 7)'. Fertile soil and balanced fertility management are major foundations for sustainable food production and contribute to sound management of natural resources and to controlling environmental degradation such as erosion, loss of biodiversity, pollution of water sources and acidification. It has been recognized that activities aimed at improving soil fertility management need to be implemented within an overall strategy to reduce poverty that includes restoring budgetary priority to agriculture as an engine of economic growth, empowering women, and promoting community-based actions that will boost agricultural production, improve nutrition, develop rural markets and infrastructure, and promote environmental sustainability. 'Africa has not yet had its green revolution,' stated Jeffrey Sachs, Director of the Millennium Project. 'We have the technology today to bring about this revolution in a totally environmentally sound manner'.

While formal agricultural research indeed has generated a vast amount of knowledge and fundamental insights in soil fertility and ways to enhance it, their adoption by smallholder farmers, especially in Africa, has remained below expectations. The research and development community has concluded that traditional transfer of technology, once successful in specific farming systems in Europe and Asia, is not the appropriate approach in the diverse smallholder farming systems in Africa. New approaches are needed in which smallholders are actively involved in the process, that focus on technology development and innovations geared to the specific physical, climatic, economic and social circumstances of smallholders and integrate this technology development in a process of improving the conducive environment for smallholders to do business.

Currently, Integrated Nutrient Management (INM) is an approach widely used by the research and development community in addressing soil fertility decline in Africa (Vanlauwe et al., 2002). The approach aims at application of the 'best' combination of available nutrient management technologies, i.e., those that are biophysically relevant, economically attractive and socially acceptable. The aim is to move away from reliance on uniform science-driven prescriptions of mineral fertilisers as the only solution to Africa's problems and to integrate science with local stakeholders' creativity in capturing opportunities provided by their local situation.

Development of soil nutrient monitoring approaches in the period 1995-2004

Soil nutrient depletion as a serious threat to the sustainability of the productivity of African farming systems was put on the agenda of policy makers and the development community in 1990 with the publication of the report 'Assessment of soil nutrient depletion in sub-Saharan Africa' (Stoorvogel and Smaling, 1990). Their report showed alarming average annual depletion rates for the continent as a whole of 22 kg ha^{-1} of nitrogen (N), 2.5 kg ha^{-1} of phosphorus (P) and 15 kg ha^{-1} of potassium (K). However, continental or even country level soil nutrient balances provide no insights for addressing these high depletion rates and this report therefore triggered a range of research and development activities on soil nutrient balances at lower scales, most often farm household and plot level. Initiatives were taken to develop a concept for a farm and plot level nutrient monitoring approach (NUTMON) that would fill knowledge gaps on nutrient flows within various farming systems and could be used as a user-friendly decision support system by various stakeholders (Smaling and

Fresco, 1993). A workshop, organised in Nairobi in 1993 with various stakeholders from Kenya, resulted in an agenda for the development of Integrated Nutrient Management (INM) practices in general (Part 2, Chapter 1) and a plan for the development of a practical nutrient monitoring tool as a support instrument to attain that goal.

In 1994, a Kenyan-Dutch team of agronomists, soil scientists and socio-economists started to translate the concepts into a concrete monitoring approach consisting of: inventory and monitoring questionnaires; a database structure with site-specific information on nutrient contents and prices of inputs and outputs; and a model to calculate nutrient balances and financial performance indicators (Part 2, Chapters 2 and 3). The first version of the NUTMON approach was developed and applied during 1995-1996 on 26 farm households in three districts in Kenya (Part 3, Chapter 4; Van den Bosch et al., 1998).

Although initially NUTMON was intended to be used as a tool in participative decision making with farmers to improve soil fertility management, this could not be realised in this first application, since all efforts were directed towards (further) development of the NUTMON model, questionnaires and software.

At the end of this first pilot project, the initiative was taken by the team to organise a conference titled 'Soil Fertility Management in sub-Saharan Africa' in Nairobi, Kenya in February 1997. During this conference the results of the NUTMON pilot project were presented, alongside various other methods, approaches and experiences in nutrient balance studies across the continent (Smaling, 1998).

The results of the pilot project and the conference stimulated the team to further develop the model. From 1997 to 1999 this was realised in two projects, 'Potentials of low-external input and sustainable agriculture (LEINUTS)' implemented in Kenya and Uganda; and 'Spatial and temporal variability of soil fertility management (VARINUTS)' implemented in Kenya and Burkina Faso. Simultaneously Wageningen UR allocated resources to further develop the NUTMON model.
During this period various modifications were introduced in the NUTMON model and software:

- The calculations of nutrient flows and balances and financial indicators were integrated into one calculation tool;
- Adjustments in some of the transfer functions: an option for an alternative transfer function for leaching (De Willigen, 2001) and options for calculating excretion by livestock;
- Options for more easy consistency checks and debugging of entered data;
- Various options to change parameters in the transfer functions such as: leaching depth, default gaseous N losses and N or K leaching from redistribution units, soil evaporation factor, etc.
- Major changes in the data-entry, background database and calculation software were introduced, aiming at improving the user-friendliness; options for reporting farm and plot level results were included, allowing quick feedback of results to the farm households and opportunities for analysis of aggregated farm-level data.

Since the NUTMON tool generated interest from many researchers and developers world-wide, it was felt necessary to document the model in detail and issue a CD-ROM with the software (NUTMON toolbox version 1) (Vlaming et al., 2001). This information was widely distributed in the research and development community.

In the LEINUTS project, NUTMON was for the first time actually applied in a participatory diagnostic process with farmers, forming the basis for participatory technology development processes (Part 3, Chapters 5 and 6). NUTMON results, in the form of individual, visualised farm reports of soil analyses, nutrient balances and financial performance parameters were used, in combination with other existing participatory tools such as transect walks, matrix ranking, nutrient flow maps, etc. Aggregated nutrient balances and financial performance indicators were used in sessions with stakeholders at district level to identify and quantify major sources of soil fertility degradation in the districts and to provide input for the formulation of development scenario's at district level.

In the subsequent period (2000-2004), the NUTMON toolbox was further developed by the team and various new versions of the software developed. A website was established, where new versions of the software were made available (www.nutmon.org). In this period the research team continued to apply the NUTMON toolbox in various project activities:

- Nutrient Monitoring in Arid and Semi-Arid Lands in Kenya (NUTSAL); 1998–2003
- Recycling urban waste in urban agriculture in Bamako and Ougadougou (APUGEDU); 1999-2002
- Policies for Sustainable Land Management in the East African Highlands; 2001-2003
- Economic Policy Reforms, Agricultural Incentives and Soil Degradation in Developing Countries (EPISODE) in China, Kenya and Ethiopia; 1999–2001
- Sustainable technologies for pest, disease and soil fertility management in smallholder vegetable production in China and Vietnam (VEGSYS); 2002-2006
- Integrated nutrient management to attain sustainable productivity increases in East African farming systems (INMASP) in Kenya, Uganda and Ethiopia; 2001–2005
- Policies for sustainable land management in Ethiopia (PIMEA); 2001–2003
- Mitigation of unresolved tensions through increased agricultural recovery assistance project (MUTIARA) in Indonesia; 2003-2005

A description of the results and experiences of two of these projects, NUTSAL and INMASP, are included in this thesis (Part 3, Chapters 7 and 8, respectively). Compared with the earlier applications of NUTMON in the pilot and the LEINUTS project, the following changes in its implementation were made (Table 1):

- The number of farm households monitored increased;
- The monitoring frequency and duration decreased;
- The focus shifted from individual farm households to group processes;
- Further integration of the NUTMON tool in participatory and learning processes .

Table 1 Overview of developments in NUTMON applications in projects described in this thesis

Project	Year	Number of farms monitored	Monitoring frequency	Duration	Entry point	Role of NUTMON
Pilot	1994 - 1995	**26** in 3 districts in 1 country	Monthly	1 year	Households	Diagnostics at farm level
LEINUTS	1997 - 1999	**30** in 4 locations in 2 countries	Monthly	2 years	Households	Diagnostics at farm and district level; priority setting in Participatory Technology Development
NUTSAL	1998 - 2003	**111** in 6 locations in 1 country	Monthly	1 year	Village/group	Diagnostics at farm and district level; priority setting in Participatory Technology Development
INMASP	2001 - 2005	**210** in 11 locations in 3 countries	once per cropping season	6 months (1 season)	Farmers Field Schools	Joint learning and priority setting in experimenting

Given the high variability in farm management practices, nutrient balances and financial performance observed among farm households in a similar area, it was felt necessary to improve the representativeness of the sample for the identified farming systems by increasing the number of farm households included in the monitoring. To reduce the time requirements of farmers and researchers, monitoring duration and frequency were reduced. Another argument to reduce the time spent on NUTMON was the focus in the later projects on action-oriented research and development, rather than on diagnostics alone and 'getting the nutrient balances right'. In the NUTSAL and INMASP projects, the NUTMON results played an important role in the group process with farmers and facilitators in observing, experimenting and learning. Various indicators of farm management practices (fertilizer, organic manure application rates, etc.) and performance indicators (yields, nutrient balances, gross margins per crop) per farm household were compared with the group average and among individual farm households, as a basis for discussions about farm management practices.

Evolving approaches in search of effective innovation systems for smallholder agriculture

The development of the NUTMON approach was influenced by changes in thinking about technology development, innovation, extension and learning processes in smallholder agriculture. Therefore a short overview of these developments is presented.

In the past decades, technological innovations have dramatically changed life for the majority of the world population, in terms of economic activities, communication, public health, mobility, nutrition, etc. In the agricultural sector, the Green Revolution has enabled feeding of and providing a livelihood for the rapidly growing population in Asia, while globalisation has drastically changed the character of the local and world market for agricultural products. Smallholder agriculture in sub-Saharan Africa (SSA) has until now, hardly benefited from these developments. On the contrary, globalisation of markets and technology has made it more difficult for smallholders in Africa to compete, participate and link up to these developments, leading to declining livelihoods and increasing poverty in many rural areas. Huge efforts, mainly by research and extension organisations, were made to initiate an 'African Green Revolution', however without much success. Developing rather uniform packages of technology, based on high-yielding, fertiliser-responsive crop varieties or capital-intensive livestock systems, appeared to be ineffective in the highly complex and variable smallholder farming systems in SSA that function in imperfect input and output marketing systems. Therefore, also the linear model of technology transfer, focusing on diffusion of innovations mainly originating from fundamental and on-station research had little impact. The training and visit system (T&V), widely adopted in Asia for more than two decades and supported by the World Bank, needed revision.

The focus shifted from developing technologies in research systems and transferring these technologies to farmers, to active participation of farmers in the research and innovation process and facilitation of experimentation among communities. The linear model based on the concept of diffusion of knowledge (Rogers, 1962), assuming farmers to be only 'adopters' or 'rejecters' of technology, was replaced by an approach in which farmers acted as partners in the technology development process, being able to provide knowledge and contribute to development of improved practices. This required new farmer-oriented approaches to innovation and decision-making, where farmers are involved in the entire process of searching for and applying solutions on technical, organisational, marketing and social issues (Jiggins, 1983). The focus on dialogue and rural innovation in research and extension is labelled by Leeuwis (2004) 'Communication for rural innovation'. In addition to the insight that existing knowledge of farmers is crucial in the innovation process, (experiential) learning and capacity building of farmers to improve upon informed and critical decision-making are considered equally crucial (Macadam, 2000). Since these processes are much more effectively realised in groups than with individuals, approaches increasingly focused on facilitating various forms of farmer organisations.

Innovation systems can be described as the system or network of private and public sector organizations whose interactions produce, diffuse and use economically useful knowledge (Hall, 2002). The component parts of the systems and their interactions are determined by the institutional setting, professional and culturally defined norms within organizations, historical patterns of institutional development and national priorities. These institutional settings are in turn defined by geographic borders and national policies. Leverage points for enhancing innovative performance include:

- The extent of interactions, partnerships and other forms of linkage;
- Impediments to flows of knowledge between organizations;
- The opportunities for and constraints to interactive learning and institutional innovation;
- Policy and practices that can give rise to failures of the component parts working as a system (Clark et al., 2003).

The value of this approach to agricultural research systems is that it allows the sector to be viewed in a much more holistic fashion encompassing the range of organizational forms and institutional settings (NGOs, farmer association, etc.).

The core elements of developing new innovation systems in smallholder agriculture, therefore consist of *farmer empowerment, experiential learning* and *farmer organisation.* Knowledge is crucial for people to gain control and power over their situation: the capability of an actor to intervene in a series of events so as to alter their course (Giddens, 1976). *Farmer empowerment* is therefore referred to as the process of gaining control (Sen, 1997). A wide array of definitions of empowerment exists (Page and Czuba, 1999; Duveskog, 2006), but an appropriate one focusing on smallholder agriculture has been formulated by Friis-Hansen (2004): 'Farmer empowerment is when farmers assume the authority, resources and capabilities to hold accountable and influence the content of public and private agricultural services, such as extension, research, training, information, investment and marketing'. A conceptual framework for empowerment consists of agency of the poor (assets and capabilities at individual and collective level), combined with opportunity structures (institutional climate and social and political structures) (Narayan, 2005). Agency is hereby defined as an actor's ability to envisage options and make meaningful choices based upon reflection and options available (Alsop and Heinsohn, 2005). At the individual level, farmer empowerment needs to address productive, financial, human and organisational assets, knowledge and self-esteem. At the collective level, farmers' organisations are central in providing platforms for joint action, enlarge access to ideas, information, expand ties to other networks and resources and strengthen the position in input and output markets. The opportunity structures are defined as the formal and informal context in which farmers have to operate and may include aspects such as access to information, inclusion and participation, accountability of officials, local organisational capacity, democratisation, response of government structures to peoples demands and aspiration (Narayan, 2005). Similar to this concept is the model of the farmer as a cognitive agent who pursues and adjusts goals and purposes on the basis of iterating through information about changing environment, her/his knowledge, and her/his perceived options for acting (Braun et al., 2006). To support and strengthen this new innovation model, approaches should aim at:

- Changing farmers' perceptions;
- Changing farmers' emotions, goals and purposes;
- Increasing farmers' knowledge;
- Strengthening farmers' capacity for action;
- Developing farmers' ability to perceive feedback;
- Building capacity to deal with conflicts.

Experiential learning is a key element in farmer empowerment and is grounded in the concept of adult education (Knowles, 1968) and focuses on incorporating learners' past experience in the process. Experiential learning is based upon Kolb's learning cycle (Kolb, 1984) that links theory and practice in a four-stage cycle (Figure 1):

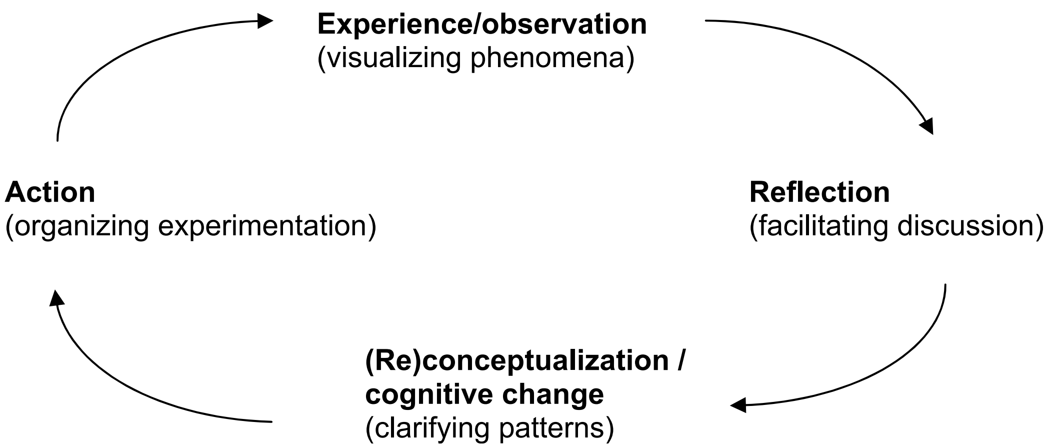


Fig. 1 The learning cycle with examples in brackets of ways in which different stages can be supported by communication workers (adapted from Kolb, 1984; Leeuwis, 2004)

In addition to experience and actual observation, the process of reflective thinking is a crucial step in the learning process: making sense out of experiences, evaluate, share with other learners. This should lead to a better understanding of what is observed and only then the process of action and experimentation can start. Action research combines pursuing change and building understanding in one combined process and consists of a common cycle of planning, action, observation and reflection/evaluation. Various more detailed visions on learning processes have been developed such as differentiating between levels of learning (trial and error, learning how to learn, understanding context; Bateson, 1972), learning relating to changing routine behaviour, learning creating changes in questioning the underlying values and policies (Argyris, 1976; Duveskog, 2006). In the specific context of Farmer Field Schools (FFS), applied in combination with NUTMON (Part 3, Chapter 8), multiple learning cycles are identified (Fig. 2).

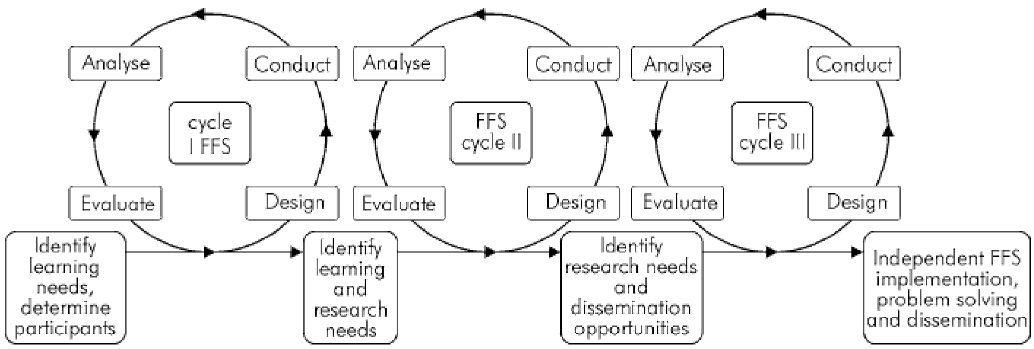


Fig. 2 Multiple FFS cycles for learning and problem solving (IIRR/FAO, 2007; adapted from Van de Fliert et al., 2001)

In addition, *farmer organisation* is an important component of the learning process, since it facilitates group processes, dialogue and in general creates a stimulating learning environment. Creating group cohesion is particularly essential in creating a safe learning environment, characterised by trust, openness, integrity, mutual respect and patience with each other. Interaction between knowledge, behaviour and social relationships is crucial, and is the process that facilitates empowerment (Bartlett, 2005; Fig. 3)

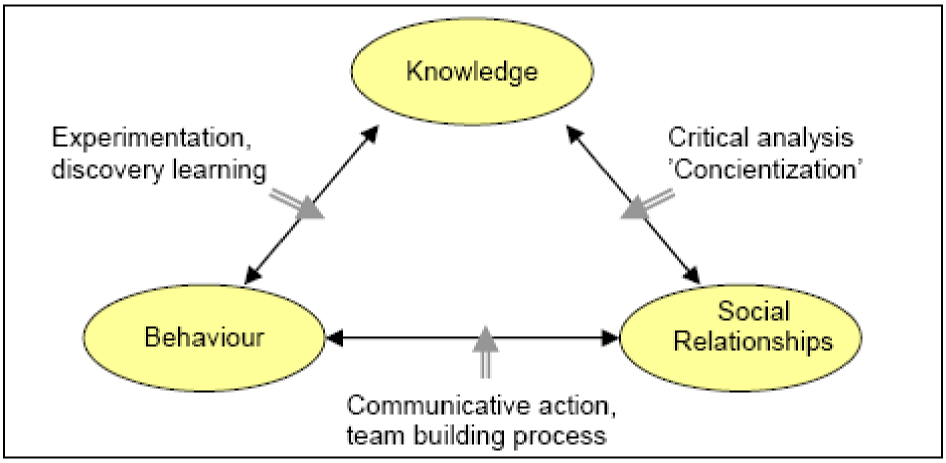


Fig. 3 Illustration of the role of social relationships in learning processes (Source: Bartlett, 2005, adapted by Duveskog, 2006)

Learning in the technical domain alone may not lead to the desired change, since the learner may not be able to apply the technical knowledge, unless he is freed from constraining factors once assumed to be out of his control and without interactions and consensus with other humans (Pontius et al., 2002). This view is illustrated by experiences described in this thesis, whereby market linkages, established through group activities, facilitated continuation of the FFS (Part 3, Chapter 8).

Learning-related development approaches, however, also have shortcomings. In the theories described above, the learning process is assumed to take place in a mode of consensus, while often differences of perceptions or conflicts of interests are intertwined with social interests and practices and therefore developing solutions to problems involves a process of negotiation (Leeuwis, 2000). The commonly used participatory approaches lack the tools for the process of negotiation. Others state that popular participatory and learning approaches are often presented as an alternative to empirical research and positive epistemologies, rather than being complementary and suggest a superiority of action-based research in bringing about change (German and Stroud, 2007).

Objectives and research questions

The overall objective of the research activities undertaken in the period 1994–2006 was to contribute to the development of ecologically and economically sustainable farming systems in East Africa by addressing soil nutrient depletion, one of the major components of natural resources degradation in the region. To achieve this objective, activities were implemented by inter-disciplinary teams of African and Dutch researchers and development agents, in a series of projects focusing on:

- Development of an inter-disciplinary diagnostic tool to quantitatively assess nutrient balances and financial performance at farm household level;
- Integration and implementation of the farm diagnostic tool into participative innovation approaches, addressing soil nutrient depletion.

This thesis is the reflection of the results of the activities carried out, and addresses specifically the following research questions:

- Is it possible to design an integrated, multi-disciplinary monitoring concept in smallholder agriculture to address natural resources management in general and nutrient management in particular?
- What features does a monitoring approach need to have in order to be easy-to-handle and to allow smallholder farmers and researchers to jointly analyse the environmental and financial sustainability of tropical farming systems?
- In which way can the results of such a monitoring approach contribute to an effective and participative innovation process, aiming at sustainable improvement of soil fertility management, farm productivity and rural livelihoods in East Africa?

Outline of the thesis

The thesis is subdivided in five parts and consists of 8 publications, one draft paper, a general discussion and concluding remarks.

Following this introduction (Part 1), in Part 2 the conceptual framework of the nutrient monitoring approach is presented. Chapter 1 provides a global classification of agro-ecosystems based on the degree of soil nutrient depletion, followed by a concept of related quantitative indicators. The research agenda presented at the end of the chapter is being addressed in this thesis. Chapter 2 describes the necessary disciplines and spatial scales for diagnosis, analysis and action to address soil nutrient depletion. A comparison is made with alternative methodologies and approaches being used at that time. Finally, Chapter 3 describes the general characteristics of the NUTMON approach that has been developed for implementation in the diagnostics at farm household level.

Part 3 describes the experiences and results of the implementation of NUTMON in combination with action-oriented approaches in various agro-ecological zones in Kenya and Uganda in the period 1995-2006:

- Monitoring performance of farming systems in three agro-ecological zones in Kenya (Chapter 4). The paper in this chapter analyses biophysical and financial sustainability aspects of farming systems in three districts in Kenya (Kisii, Kakamega, Embu) in the period 1995-1996. Farming systems characteristic, nutrient flows and balances and financial performance indicators were analysed at farm and activity level and correlations between them explored;
- Assessing sustainability of low-external input farm management systems in Machakos District, Kenya (Chapter 5). The paper in this chapter presents both the NUTMON diagnostic and technology development steps of the NUTMON approach. Its use is illustrated in a study in Kenya comparing conventional with low-external-input farm management. The NUTMON tool and its various modules are described in detail, while also the participatory approaches on how to use the model results in analysing farming systems and developing new and appropriate technologies with farmers are described;
- Potentials of low-external input technologies in four agro-ecological zones in Kenya and Uganda (Chapter 6). This chapter describes a case study in four districts in Kenya and Uganda during the period 1997–1999, where the potentials of low-external-input technologies (LEIA) in addressing soil nutrient depletion were assessed. It includes the experiences with learning processes of farmers and policy makers to use various diagnostic and participatory tools to develop technologies and facilitating policies;
- Attaining sustainable farm management systems in semi-arid areas in Kenya (Chapter 7). This chapter describes the application of the NUTMON approach to

address soil fertility degradation problems in semi-arid areas in Kenya in the period 1998-2003. Instead of individual farmers, groups of farm households participated in the activities including regular feedback and discussions with the whole village community.

- Farmers Field Schools and Integrated Nutrient Management in Kenya (Chapter 8). The paper in this chapter describes experiences and results of a project implemented in Kenya, Uganda and Ethiopia in the period 2002 – 2006, in which the group approach was further developed and FFS were taken as entry-point to address soil fertility degradation.

Part 4 evaluates the lessons learnt from the various field activities addressing soil fertility management and attempts to relate technology development to facilitating policies, market developments, institutional aspects and value-chain processes.

The thesis concludes (Part 5) with an evaluation of the approach in relation to alternative methods and a description of the envisaged future developments. Subsequently, the role of NUTMON and participatory research approaches such as FFS in developing effective innovation systems in smallholder agriculture and the options for implementation in Africa are discussed. Concluding remarks address the way forward in research and development towards more sustainable rural livelihood strategies in East Africa.

Literature

Alsop, R. and Heinsohn, N., 2005. Measuring empowerment in practice: structuring analysis and framing indicators. Washington DC, USA: The World Bank.

Argyris, C., 1976. Theories of action that inhibit individual learning. American Psychologist 39, 638-654.

Bartlett, A., 2005. No more adoption rates! Looking for empowerment in agricultural programmes. Impact Assessment Workshop. Mexico: CIMMYT.

Bateson, G.,1972. Steps to an ecology of mind. San Francisco, USA: Chandler.

Braun, A., Jiggins, J, Roling, N., Van den Berg, H., and Snijders, P., 2006. A global survey and review of Farmer Field School experiences. Wageningen, The Netherlands: Endelea.

Clark, N., Hall, A., Sulaiman, R. and Naik, G., 2003. Research as capacity building: the case of an NGO facilitated post-harvest innovation system for the Himalayan hills. World Development 31 (11): 1845-1863.

De Willigen, P., 2000. An analysis of the calculation of leaching and denitrification losses as practised in the NUTMON approach. Report No. 18, Wageningen, The Netherlands: Plant Research International.

Duveskog, D., 2006. Theoretical perspectives of the learning process in Farmer Field Schools; with reference to East African experiences. Working Paper, Rome, Italy: FAO.

Friis-Hansen, E., 2004. Concepts and experiences with demand-driven advisory services. A review of recent literature with examples from Tanzania. DIIS Working Paper 2004/7, Copenhagen, Denmark.

German, L. and Stroud, A., 2007. A framework for the integration of diverse learning approaches: operationalizing agricultural research and development linkages in East Africa. World Development 35, 792–814.

Giddens, A., 1976. New rules of sociological method: a positive critique of interpretative sociologies. Hutchinson, London.

Hall, A. J., 2002. Innovation systems and capacity development: agenda for North–South research collaboration? International Journal of Technology Management and Sustainable Development, 1(3): 146–152.

IIRR/FAO, 2007. Discovery-based Learning in Land and Water Management; A Practical Guide for Farmer Field Schools. (in press)

Jiggins, J., 1983. Poverty-oriented rural development: participation and management. Development Policy Review 1, 219-252.

Knowles, M.,1968. Androgogy, not pedagogy!. Adult Leadership 16, 350-352.

Kolb, D., 1984. Experiential learning. New Jersey, USA: Prentice Hall, Inc.

Leeuwis, C., 2000. Reconceptualizing participation for sustainable rural development: towards a negotiation approach. Development and Change 31, 931–959.

Leeuwis, C., 2004. Communication for Rural Innovation: rethinking agricultural extension. Oxford, UK: Blackwell Science Inc.

Macadam, R. D., 2000. From pushing production inputs to empowering the community: a case study in the transformation of an extension agency. Australian Journal of Experimental Agriculture 40, 585-594

Narayan, D., 2005. Measuring empowerment, cross-disciplinary perspectives. Washington DC, USA: The World Bank.

Page, N. and Czuba, C., 1999. Empowerment: What is it?. Journal of Extension 37(5).

Pontius, J., Dilts, R. and Bartlett, A., 2002. From farmer field school to community IPM. Ten years of IPM training in Asia. Bangkok, Thailand: FAO Regional Office for Asia and the Pacific.

Rogers, E. M.,1962. Diffusion of Innovations. New York, USA: Free Press.

Sen, G., 1997. Empowerment as an approach to poverty. Bangalore, India: Indian Institute of Management.

Smaling, E.M.A. (ed), 1998. Nutrient balances as indicators of productivity and sustainability in sub–Saharan African agriculture. Agriculture, Ecosystems and Environment 71 (1-3), (special issue), 235 pp

Smaling, E.M.A. and Fresco, L.O., 1993. A decision-support model for monitoring nutrient balances under agricultural land use (NUTMON). Geoderma 60, 235-256.

Stoorvogel, J.J. and Smaling, E.M.A., 1990. Assessment of soil nutrient depletion in Sub Saharan Africa, 1983 – 2000. Volumes I-IV. Wageningen, The Netherlands: The Winand Staring Centre.

Van de Fliert, E., Johnson, N., Asmunati, R., and Wiyanto, 2001. Beyond Higher Yields: The Impact of Sweet potato Integrated Crop Management and Farmer Field Schools in Indonesia. In: CIP, Scientist and Farmer: Partners in research for the 21st century. Program Report 1999-2000, pp. 331-342. Lima, Peru: International Potato Center.

Van den Bosch, H., Gitari, J.N., Ogaro, V.N., Maobe, S. and Vlaming, J., 1998. Monitoring nutrient flows and economic performance in African farming systems (NUTMON). III. Monitoring nutrient flows and balances in three districts in Kenya. Agriculture, Ecosystems Environment 71, 65 – 82.

Vanlauwe, B., Diels, J., Sanginga, N. and Merckx, R. (eds.), 2002. Integrated Plant Nutrient Management in Sub-Saharan Africa. From Concept to Practice. New York, USA: CABI Publishing, 352 pp.

Vlaming, J., Van den Bosch, H., Van Wijk, M.S., De Jager, A., Bannink, A. and Van Keulen, H., 2001. Monitoring nutrient flows and economic performance in tropical farming systems (NUTMON). Part 1. Manual for the NUTMON-toolbox; Part 2. Annex. Wageningen/Den Haag, The Netherlands: Alterra/LEI.

PART 2 Conceptual framework of NUTMON approach

Chapter 1 Concept and classification of soil nutrient stocks and flows

Smaling, E.M.A., Fresco, L.O., and De Jager, A., 1996

Classifying, Monitoring and Improving Soil Nutrient Stocks and Flows in African Agriculture.

Ambio 25 (8): 492 – 496.

Eric M.A. Smaling, Louise O. Fresco and Andre de Jager

Classifying, Monitoring and Improving Soil Nutrient Stocks and Flows in African Agriculture

Nutrient stocks and budgets (positive minus negative flows) are quantifiable indicators of sustainability, and are applied in this paper to classify agro-ecosystems. Earlier work revealed that most agricultural systems in sub-Saharan Africa (SSA) can be labelled nonsustainable due to low nutrient stocks and negative nutrient budgets. To increase production and build sustainable agro-ecosystems in SSA, technologies that rank under "integrated nutrient management" (INM) should be adopted, to save nutrients from being lost, and to add new nutrient supplies to the system. An account is given of the socioeconomic factors at national and farm level, the interplay of which determines the actual adoption rate of INM. Based on an overview of what we do know and what we don't know, an INM research agenda is proposed that is based on the knowledge gaps.

INTRODUCTION

Today's environmental problems of pollution, degradation and depletion of natural resources have enhanced global awareness that the buoyancy of the world's agro-ecosystems is finite. Agenda 21, the legacy of the 1992 UN Conference of Environment and Development in Rio, describes a series of environmental issues to be addressed and avenues to be followed to move closer to "sustainable development" by the year 2000. Chapter 14 specifically deals with sustainable agriculture and rural development. Programme area J deals with "sustainable plant nutrition to increase food production", and singles out sub-Saharan Africa (SSA) as the subcontinent that is losing soil fertility at an alarming rate.

In SSA, where the agricultural sector generates the lion's share of Gross National Product (GNP), it is increasingly difficult to satisfy production and sustainability demands at the same time. Farmers are primarily concerned about the crop and animal production potential for the forthcoming season, because disappointing output has immediate financial and nutritional implications for their families. Longer-term processes that affect sustainability adversely, such as decreasing soil organic matter levels and nutrient reserves, however, are much less visible and may therefore seem less noteworthy to the farmer. Although SSA farmers are usually well aware of detrimental effects of, for example, decreasing fallow rates, they generally fail to invest in long-term soil fertility for reasons such as lack of land property rights, immediate cash needs, risk aversion and labor shortage.

Whereas soil research in SSA used to be focused on soil fertility *per se,* it has of late clearly been given a spatio-temporal dimension. The vast majority of researchers have concluded that, on a per hectare per year basis (ha^{-1} yr^{-1}, negative nutrient flows or outputs exceed positive nutrient flows or inputs, rendering most agro-ecosystems nonsustainable (1-8). A FAO-initiated assessment of the nitrogen (N), phosphorus (P), and potassium (K) budget (positive flows minus negative flows) for 35 crops in 38 SSA countries gave a net negative budget ha^{-1} yr^{-1} of 22 kg N, 2.5 kg P, and 15 kg K in the period 1982-1984 (9, 10). In other words, soil fertility in SSA is at stake! Yields may still be good in places, but the soil nutrient stock is gradually being depleted to levels that can soon no longer sustain a still growing African population. In the Sahel and Sudan Savanna zones of West Africa, it seems we have come close to that point.

Fortunately, nutrient stocks and flows can be manipulated. When done judiciously, we talk of integrated nutrient management (INM). The extent to which a farm household adopts INM determines not just whether high farm output can be realized (production goal), but also whether production can remain high in the long run (sustainability goal). In this text, we first present a static classification of agro-ecosystems on the basis of their nutrient stocks and flows. Next, we list several components of INM-based farming systems that maintain or improve soil fertility. The latter basically pertains to farm management strategies that save nutrients from being lost from the system (e.g. erosion control, restitution of residues, recycling of manure within the farm) or interventions that add nutrients from outside (e.g. fallowing, mineral fertilizer application, biological N fixation). Mixtures also exist (e.g. agroforestry, zero-grazing). The likelihood of INM to be adopted is governed by the socioeconomic conditions at both the macro-level (e.g. market access, enabling environment) and at the micro-level (e.g. price ratios between inputs and outputs, efficient allocation of labor). Hence, it is imperative to know the existing socioeconomic boundaries at each system level and the required conditions to successfully campaign for INM.

Based on the foregoing, a research and development agenda is formulated to further study and promote the adoption of INM systems in SSA. Key to the INM agenda is the development and operationalization of a decision-support system for nutrient monitoring (NUTMON), ingredients of which were published

Table 1. Nutrient flows at different spatial scales (input = +; output = -; neutral = o).

	Country	Farm	Soil solution
1. mineral fertilizers			
a. *highly soluble*	o/+	+	+
b. *less soluble*	o/+	+	o
2. fodder			
a. *concentrates*	o/+	+	o
b. *roughage/grasses*	o	o/+	o
3. animal manure			
a. *dung*	o	o/+	o
b. *urine*	o	o	+
4. deposition			
a. *precipitation*	o/+	+	+
b. *dust*	o/+	+	o
5. biological N fixation			
a. *nonsymbiotic*	+	+	o
b. *symbiotic*	+	+	o
6. sedimentation	o/+	+	o
7. economic product			
a. *plant*	–/o	–	o
b. *animal*	–/o	–	o
8. crop residue removal			
a. *burning*	–	–	o
b. *fed to livestock*	o	o	o
c. *sold as mats/baskets*	o	–	o
9. water erosion	–/o	–	o
10. leaching	–	–	–
11. gaseous losses	–	–	–
12. nutrient uptake	o	o	–
13. desorption	o	o	+
14. sorption	o	o	–
15. mineralization	o	o	+
16. immobilization	o	o	–
17. weathering	o	o	+
18. chemical fixation and precipitation	o	o	–

earlier (11). To turn NUTMON into an operational tool for all stakeholders in the field of land-use planning and sustainable agriculture, the INM agenda needs to be implemented at full force in different agro-ecological zones in SSA.

SPATIAL AND TEMPORAL AGRO-ECOSYSTEM BOUNDARIES

Nutrient flows occur at every spatial agro-ecosystem level. Examples are the mineralization of organic N and subsequent uptake by a plant root, application of animal manure from the farm stable to coffee stands, milk sold by a farmer to the factory, and national food imports. Three different spatial scales (country, farm, soil solution) are presented in Table 1. At each level, different processes determine the actual value of the nutrient budget. Concentrates purchased to feed stalled cattle, for example (2a in Table 1), may have been produced overseas, but may just as well have been produced within the country (*+/o*), whereas at a lower system level, they do enter the farm gate (+). Roughage (2b in Table 1) such as napier grass, is grown within the country (o), whereas it can be grown on the farm or purchased from a neighbor *(o/+)*. Water erosion at farm level is a negative nutrient flow (-). The eroded material may end up in the ocean and be lost for good, but it may also become an input through sedimentation on floodplain farms in the lower reaches of the river basin (+). Table 1 shows that processes 12 to 18 are neutral at country and farm level (o), but all play a role at the soil solution level. The nutrient budget at this level is a reflection of the actual availability of nutrients to plants.

The nutrient budget concept also relates to different temporal scales. Agro-ecosystems that comprise long-fallows, for example, need not be balanced annually. A negative budget, in one or a few years, is acceptable as long as the following years are used for restoring soil fertility. When considering ecological and geological time scales, however, equilibrium situations as to nutrient budgets hardly exist as climate change, volcanism, and biodiversity development all have their more or less gradual impact on agro-ecosystems (12).

CLASSIFYING AGRO-ECOSYSTEMS ON THE BASIS OF NUTRIENT BUDGETS

At each agro-ecosystem level (country, catchment area, farm, plot, soil solution), a nutrient budget can be drawn up, with a sum of inputs that may exceed, equal or be lower than the sum of outputs. Table 2 lists the nutrient inputs, outputs and internal flows that can play a role at farm level, more or less summarizing the central column of Table 1. The following nutrient budget classification is meant to cover all possible nutrient surplus, equilibrium, and deficit situations.

Table 2. Nutrient flows at farm level.

Nutrient inputs	
IN 1	Mineral fertilizers
IN 2	Organic inputs, subdivided into:
IN 2a	concentrates for livestock and fish
IN 2b	other organic feeds for livestock and fish
IN 2c	urban and agro-industrial waste
IN 2d	manure obtained from outside the farm
IN 2e	manure from farm livestock grazing outside the farm during part of the day
IN 2f	food for the farm family obtained from outside the farm
IN 3	Atmospheric deposition in rain and dust
IN 4	Biological nitrogen fixation in leguminous species (including free-living bacteria)
IN 5	Sedimentation as a result of (i) irrigation; (ii) natural flooding; or (iii) partial resedimentation of soil materials eroded from upper slopes
IN 6	Subsoil exploitation by trees and other perennial crops
Nutrient outputs	
OUT 1	Harvested crops, meat, milk, and fish, leaving the farm
OUT 2	Crop residues and manure leaving the farm
OUT 3	Leaching below the root zone
OUT 4	Gaseous losses (including denitrification, ammonia volatilization, and losses as a result of burning)
OUT 5	Runoff and erosion
OUT 6	Human faeces ending up in deep pit latrines
Internal flows	
FL 1	Crop residues fed to tethered farm animals or applied to certain plots
FL 2	Biomass from plots under pasture and fallow eaten by roaming farm animals
FL 3	Animal manure from within the farm applied to certain plots
FL 4	Crops, milk, meat and fish obtained from the farm, eaten by the farm family
FL 5	Food remnants and farmyard manure applied to certain plots

Table 3 Nitrogen budgets (kg ha^{-1} yr^{-1}) for former West Germany (1986) and Tanzania (1982-1984)

	West Germany	Tanzania
Inputs		
Mineral fertilizers	126	2
Animal manure	47	1
Wet and dry deposition	30	3
Biological N fixation	12	4
Other	3	0
Total	218	10
Outputs		
Plant and animal production	51	17
Leaching, runoff, erosion	51	15
Gaseous losses	69	5
Total	171	37
Nitrogen budget	+47	-27

Class I: $\sum$ in - $\sum$ out > 0

Net accumulation of nutrients is found in countries where mineral fertilizers (IN 1) and imported feedstuffs (IN 2a, 2b) are commonly used, and where atmospheric deposition (IN 3) is high due to air pollution. Table 3 shows how nutrient inputs grossly exceed nutrient outputs for agro-ecosystems in former West Germany (13). In SSA, positive nutrient budgets are largely restricted to within-farm movement of nutrients, such as the concentration of manure and household waste in home gardens and other fields close to the homestead (IN 2e, FL 2,3,5). Floodplains and irrigated land may receive more nutrients than they lose in the case of high-input rice or vegetable cultivation (IN 1,2,5), and in case they receive sediments from the upper reaches of the river basin (IN 5). In the vicinity of towns and agro-industrial sites, crops may receive substantial amounts of organic waste and compost originating from these nearby sources (IN 2c), which may rank them in Class I as well.

Class II: $\sum$ in - $\sum$ out = 0

The long-term equilibrium is typical of more or less "closed" systems, such as tropical rain forests and undisturbed savannas. Slight disturbances do not necessarily disrupt equilibria, as in the case of traditional long fallows. Where land is not scarce, the farmer leaves a plot as soon as its productivity dwindles, and subsequently shifts to a neighboring plot that bas been idle during the previous years, gaining free fertility from atmospheric deposition (IN 3) and biological N f1Xation (IN 4). Any deficit in the nutrient budget of the cultivated plot is offset by gains from processes occurring during fallow periods. The nutrient pool may thus become fully replenished if fallow periods are long enough. Perennial agro-ecosystems dominated by high-input cash crops (IN 1; tea, coffee, oil palm) may be close to equilibrium for some nutrients, provided that management and input levels are high and losses through OUT 2-5 are minimized (e.g. mulching, cover crops, minimum tillage). Controlled grazing of improved pastures, preferably including leguminous species such as *Desmodiurn* (IN 4), may also lead to a Class II situation. The same holds for extensive grazing, as long as stocking rates are a reflection of the carrying capacity of the particular area.

@ Royal Swedish Academy of Sciences 1996

Class III: ∑ in -∑ out < 0

Systems with negative nutrient budgets are widespread in SSA, ranging from the low-input food crop areas in the Sahel to the East African Highlands. FAO and World Bank statistics show that nearly 50% of the production increases in SSA realized during the past three decades resulted from area expansion, as opposed to 30% in Latin America and a mere 6% in East Asia. Meanwhile, fertilizer use in 1990 was 9 kg ha^{-1}, as opposed to 47 kg ha^{-1} in Latin America, and 190 kg ha^{-1} in East Asia. In Tanzania's arable land (Table 3), nitrogen outputs in crop and animal products alone (17 kg ha^{-1} yr^{-1}) amount up to almost twice the sum of all inputs (10 kg ha^{-1} yr^{-1}). At this stage, some further partitioning is necessary as some areas in SSA are still highly productive, yet they fa1l in Class III. This subclassification is restricted to the macronutrients N and P.

Class IIIa: plant available N and P > crop requirements

In Class IIIa the effects of nutrient depletion on yields are masked by the buffering effect of the soil's (still adequate) nutrient stocks. In areas that fall in this class, high agricultural production can be maintained for many years. A recently cleared Cambisol on the slopes of Mount Elgon in Western Kenya, for example, had a nitrogen stock of approximately 6000 kg N ha^{-1}. Assuming an annual mineralization rate of 3%, leaves the considerable amount of 180 kg N ha^{-1} available for plant uptake, and for offsetting negative nutrient budgets. Under continuous cultivation, some point in time will be reached, however, when organic matter and mineralized N can no longer buffer the production system, and the agro-ecosystem will be relegated to Class IIIb or IIIc.

Class IIIb: plant available N or P < crop requirements

This situation is reached as soon as the stocks of N and P are imbalanced. The Nitisol in Table 4 has a low P/N ratio. The table shows that the uptake of N and crop yields increased strongly on application of P fertilizer. Evidently, at a low P status only a fraction of the potentially available N is taken up by the crop. Although the N budget is negative, there is no point in adding N to the Nitisol as long as P is in short supply, as it will be lost anyway through one of the processes OUT 2-5 (Table 2). On applying P to this soil, the P/N balance may be restored and uptake of soil N by the crop (OUT 1) and yields may increase considerably, fulfilling a production target. The Vertisol in Table 4 has a high P/N ratio, but the same principle applies. Addition of fertilizer-N to this soil increases both the uptake of soil P and crop yields. Class IIIb is an important class, as soils with nutrient imbalances are widespread. The primary concern in this particular case should be balanced plant nutrition, followed by maintenance of the nutrient balance.

Table 4. Soil properties (0–20 cm layer), maize yield (kg ha^{-1}; 1990 data) and total aboveground nutrient uptake (N, P and K kg ha^{-1}) at different N and P fertilizer rates applied to three Kenyan soils.

	Nitisol	Vertisol	Arenosol
Soil properties			
org. C (g/kg)	27.0	27.3	6.3
N total (g/kg)	2.6	2.0	0.6
P-Olsen (mg/kg)	2.3	9.7	1.5
Exch. K (mmol/kg)	5.5	14.2	2.5
pH (H_2O)	5.2	7.9	7.2
sand (%)	25	25	88
silt (%)	32	10	6
clay (%)	43	65	6
Treatment	*Maize yields*		
N0 P0	2110	4570	2550
N0 P22	4860	4720	2270
N50 P0	2290	6300	2240
N50 P22	5250	7190	3730
	Nitrogen uptake		
N0 P0	42	63	26
N50 P0	50	109	36
N0 P22	79	70	47
N50 P22	79	114	59
	Phosphorus uptake		
N0 P0	5	24	3
N50 P0	6	35	4
N0 P22	12	23	11
N50 P22	11	38	12
	Potassium uptake		
N0 P0	30	95	26
N50 P0	36	126	30
N0 P22	58	106	34
N50 P22	58	133	51

Class IIIc: plant available N and P < crop requirements

As a result of both increasing population pressure and lack of yield increases per unit area, the vast majority of SSA agro-ecosystems falls in this class, which is characterized by negative nutrient budgets and, most importantly, low nutrient stocks. Table 4 shows the low levels of N and P in the Arenosol at the Kenyan Coast, and also demonstrates that substantial maize yield increases are only obtained when both nutrients are applied. Without nutrient inputs, there will be a further decline of the N and P stocks here, reducing both crop production potential as well as the number of options to build sustainable systems. In the vast millet, sorghum and groundnut growing areas of semiarid West Africa, for example, nutrient stocks are low and nutrient budgets are negative for at least N and P, because farmers apply very low amounts of nutrients from external sources (2-4). Prudencio, however, highlighted West-African farmers' survival strategies by making optimal use of farm-level spatial variation (14).

In general, however, due to lack of volcanic rejuvenation, most nonalluvial soils outside the Rift valley zone are inherently poor and fragile. In the absence of external inputs and nutrient conservation, decreasing fallow rates lead to a further depletion of the already scarce nutrient reserves. At some stage, other soil properties (organic matter content, soil structure, soil biology) will also have deteriorated to the extent that whatever remains is virtually beyond repair.

INTEGRATED NUTRIENT MANAGEMENT: WHAT WE DO KNOW

Technologies

Researchers and farmers already know much about INM technologies. The first option to increase agricultural production is by intensifying production in fertile environments (Classes I, II and IIIa), such as inland valleys.(Fr. *bas fonds),* home gardens (Fr. *champs de case),* labor-intensive horticultural areas in urban peripheries, and environments that are highly responsive to one particular input (Class IIIb), such as the P-deficient volcanic soils of the East African Highlands. Theoretically, long-fallows could then be maintained or reinstated in the more fragile environments (Class IIIc). Other options always boil down to INM, i.e. the manipulation of nutrient stocks and flows. A number of INM-based components of farming systems in Kenya and their characteristics are listed below.

Zero-grazing

- though both capital-intensive and labor-intensive, high milk (and meat) production, the socioeconomic importance of possessing livestock, and the possession of land titles together constitute a clear socioeconomic incentive;
- cross-bred dairy cattle are kept in zero-grazing units and fed fodder grasses, grown on the farm, and purchased concentrates; a large percentage of the nutrients involved are recycled as manure;
- if fodder grasses are planted on contour bunds, water erosion can be strongly reduced; similarly, the absence of free range saves nutrients as anti-erosion structures are not damaged, whereas manure does not reach the land in patches.

Agroforestry

- trees potentially provide building poles, fuelwood, fodder, fruits, shade, etc.; species such as *Calliandra, Sesbania, Leucaena* (all leguminous species) and *Grevillea* are high1y valued by farmers; in other words, the socioeconomic incentive is tangible;
- trees may increase biological N fixation, reduce leaching and water erosion, and add nutrients to the topsoil from layers not accessible to the roots of annual crops;
- interactions between agroforestry system components are still poorly quantified (presently one of the key research areas of the International Centre for Research on Agroforestry).

Soil conservation

- government policies and extension services have to play (and have played) a crucial role, as there is no direct socioeconomic incentive for the farmer;
- farmers collaboratively undertake soil conservation works at catchment level (hand-dug terraces, contour bunds, ploughed strips, grass strips, cover crops and mulching); labor availability is crucial for the success of soil conservation programs (15,16);
- few attempts have been made to turn data on annual soil loss per hectare into nutrient and productivity loss; physical data on land degradation are of little use to decision-makers unless transformed into units comparable with the cost of soil conservation.

Organic inputs

- there is a wide array of materials to be applied/recycled; farmers' perceptions on importance and type of organic inputs differ from place to place;
- synchronization of nutrient release from organic matter inputs with momentary crop nutrient demand is still poorly quantified (presently one of the key research areas of the Tropical Soil Biology and Fertility Programme).

Mineral fertilizers

- applying the right type and amount of mineral fertilizers at the right time, based on knowledge of inherent soil fertility and pH, may considerably raise production per unit area; the economic incentive is obvious, although abolishment of subsidies due to structural adjustment policies has recently reduced interest;
- if combined with nutrient-saving techniques such as manuring and erosion control, mineral fertilizers are used more efficiently.

We consider it important to group the options at hand into those that are merely saving nutrients, such as erosion control, restitution of residues, manuring, and those that are adding new supplies of nutrients to the system, such as fertilizer application, concentrates fed to livestock, sediments in floodwater, and inclusion of N-fixing species. Some options may have characteristics of both (e.g. agroforestry, zero-grazing). As each tract of agricultural land has its own agro-ecological potentials and limitations, the number of INM options to build sustainable agro-ecosystems is highly location-specific. In the East African Class IIIa and IIIb systems with reliable rainfall and deep soils, more options are available to safeguard productivity than in Sahelian Class IIIc systems with erratic rainfall and sandy or shallow soils. At farm household level, however, microclimate and soil fertility of individual plots can be considerably modified by the farmer. Individual households can be strikingly active and innovative, making use of indigenous knowledge to adjust their farming practices to the fast-changing agro-ecological and economic conditions.

The Need for an "Enabling Environment"

Government policy and implemented policy instruments largely determine the socioeconomic environment of rural farm households engaged in the agricultural production and marketing process. Adoption of technologies for implementation of INM practices is largely determined by these socioeconomic factors: short-term profitability of the technology, availability of appropriate credit facilities and inputs, extension services, marketing systems and price fluctuations, social acceptability, etc.

Although IMF-imposed structural adjustment policies currently restrict direct influence on the market (price regulation), other instruments to facilitate adoption of INM practices remain at the disposal of national governments, such as:

- giving priority to INM practices in the research and development agenda of National Agricultural Research Stations and Extension Services;
- providing necessary rural infrastructure to facilitate an efficient marketing process and increase market access;
- supporting and assisting the establishment of appropriate credit facilities;
- establishment of unambiguous land-tenure policies;
- stimulating investments in regional soil conservation projects;
- creating awareness of the long-term effects on soil nutrient mining.

Given the urgency of the situation, particularly on Class IIIc-land in the drier parts of West Africa, government-supported capital investments in nutrient stocks should be considered. In this context, mention should be made of a recent World Bank-initiated economic analysis of the feasibility of (rock) phosphates as a capital investment in SSA (17).

Economics of Technical Solutions

Cost-benefit analyses of technical options for INM require long-term estimations of the costs of lost nutrients and especially the foregone benefits of depleted soils. It is essential to differ between the short-term cost-benefit analysis, which a farm household makes when deciding to adopt a technology, and the long-term sustainability at farm household and at national levels.

For the short-term decision making the traditional cost-benefit analysis can explain most farm household behavior. The marginal costs of mineral fertilizers (IN 1), for example, are compared to the additional output realized in the crop or crop mixture. In general, addition of nutrients through mineral fertilizers considerably raises productivity per unit area. Applying the right type of fertilizer at the right time will induce more nutrients to be taken up by the crop (Table 4). The apparent effectiveness of mineral fertilizers is, however, not reflected in the average application levels. Whereas the availability of fertilizers was often restricted in the 1980s, it is currently the value-cost ratio that is the limiting factor. With the introduction of the structural adjustment policies, value-cost ratios of fertilizer use on maize in most West African countries declined seriously to values below 2, often regarded as a minimum value for adoption at farm household level (18).

The translation of the long-term sustainability effects in economic terms at farm household and at national levels is much more difficult to quantify. Interesting attempts have recently been made to estimate the future loss of production due to degradation (19-22), and to calculate the replacement cost of depleted nutrients (7). Much cited is the work by Stocking, who found that on a ha^{-1} yr^{-1} basis, the financial cost of water erosion (OUT 5) in Zimbabwe varied from USD 20 to USD 50 on arable land, and from USD 10 to USD 80 on grazing land (23). N and P losses from arable land were about three times the level of total fertilizer application in Zimbabwe, not including losses of nutrients dissolved in runoff water. Erosion thus has a massive hidden cost on the economy of Zimbabwe. From a policy viewpoint, there is a need to calculate the negative impact of unchecked

@ Royal Swedish Academy of Sciences 1996

erosion, i.e. the real on-site and off-site costs of degradation processes and, as a consequence, the potential benefits of conservation investments (21). In the East African Highlands, Kenya is ahead in the field of land adjudication, which is clearly reflected in the active interest in soil conservation (15, 24). Moreover, labor availability proved so crucial for soil conservation programs to succeed that a relatively high population density is even an asset rather than a liability (16).

Although all this knowledge is on the table, little has been turned into (inter)national policies. Contributions from agriculture to the national income are still merely based on the monetary value of commodities, and expressed in average *per capita* domestic product. Meanwhile, at farm household level, the short-term economic calculations will continue to determine (non-) adoption of INM practices. Inclusion of long-term sustainability aspects in assessing government policies and large-scale projects, however, is indispensable to change the socioeconomic environment of the farm household in favor of the much-needed implementation of INM practices.

INTEGRATED NUTRIENT MANAGEMENT: WHAT WE DON'T KNOW YET

Although much is known on INM technologies as such, few attempts have been made to systematically monitor and evaluate their impact on long-term soil productivity. Increased knowledge on the spatio-temporal dynamics of nutrient stocks and INM technologies at plot, farm and even district level or above are needed to institutionalize INM strategies by means of decision-support systems. Such systems not only compare technologies, but also indicate what it takes for a farm household to implement the technology under more or less enabling boundary conditions, or how a provincial administration could assist to overcome certain farm-level constraints. The ingredients for the technology side of such a decision-support system were published earlier as the NUTMON (NUTrient MONitoring) model (11).

The challenge of the INM agenda is to avoid reductionism, turning complex problems into models that provide a simplified simulation of reality. A complex multi-scale and multi-disciplinary topic such as INM is easily partitioned into well-researcheable bits and pieces, but it is more difficult to put the research results back into the subjective "reality" of different land use stakeholders. Next, interaction between different system levels is weakly developed, for example the impact of district and national policies on farm household decision making and vice versa, or the importance of spatial variability of natural resources at different land-use planning levels.

In our view, the INM agenda should in the first place focus on the farm household level, where all relevant decisions concerning nutrient management are taken. Modelling approaches can be used to structure complicated processes at farm level, but in a constant feed-back with real-world situations. Priority must be given to simple models that can be run in low-data environments. Based on the above considerations, the INM agenda for SSA may take the following shape:

I. collect and monitor biophysical data and processes at plot and farm level to fill knowledge gaps on the nutrient flows mentioned in Table 2;
II. monitor objectives and strategies of farm households as regards relations between farm income, food security and INM;
III. monitor macro-level policies and how they fit the concept of "enabling environment" and their impact on the adoption of INM strategies at farm level;
IV. define and fill knowledge gaps on INM technologies and particularly on powerful combinations of technologies;
V. refine the NUTMON model (11) into a user-friendly decision-support system, accessible and digestible to all stakeholders in an area;
VI. develop scenarios to compare INM systems with "business as usua1" systems, a1so including externalities, in order to sensitize the globa1 community and convince development banks and donors that maintenance and improvement of soil productivity in SSA is everybody's business.

REFERENCES

1. André, M., Gerner, H. and Dahoui, K. 1991. *Approvisionnement, commercialisation et demande des engrais au Burkina Faso.* International Fertilizer Development Center- Africa, Lomé, Togo.
2. Lompo, F. 1993. *Contribution à la valorisation des phosphates naturels du Burkina Faso: études des effets de l'interaction phosphates naturels--matières organiques.* PhD thesis, University of Abidjan, Ivory Coast.
3. Pieri, C. 1989. *Fertilité des terres de savanes.* Ministère de la Coopération et CIRAD- IRAT, Montpellier, France.
4. Sédogo, P.M. 1993. *Evolution des sols ferrugineux lessivés sous culture: incidence des modes de gestion sur la fertilité.* PhD thesis, University of Abidjan, Ivory Coast.
5. Smaling, E.M.A. 1993. *An Agro-ecological Framework for Integrated Nutrient Management, with Special Reference to Kenya.* PhD thesis, Agricultural University, Wageningen, The Netherlands.
6. Van Keulen, H. and Breman, H. 1990. Agricultural development in the West African Sahelian region: a cure against land hunger? *Agric. Ecos. Envir.* 32,177-197.
7. Van der Pol, F. 1992. *Soil Mining. An Unseen Contributor to Farm Income in Southern Mali.* Bulletin 325, Royal Tropical Institute, Amsterdam, The Netherlands.
8. Van Reuler, H. and Prins, W.H. 1993. *The Role of Plant Nutrients for Sustainable Food Crop Production in Sub-Saharan Africa.* VKP , Leidschendam, The Netherlands.
9. Stoorvogel, J.J. and Smaling, E.M.A. 1990. *Assessment of Soil Nutrient Depletion in Sub-Saharan Africa,* 1983-2000. Report 28, DLO Winand Staring Centre for Integrated Land, Soil and Water Research (SC-DLO), Wageningen, The Netherlands.
10. Stoorvogel, J.J., Smaling, E.M.A. and Janssen, B.H. 1993. Calculating soil nutrient balances at different scale. I. Supra-national scale. *Fert. Res.* 35, 227-235.
11. Smaling, E.M.A. and Fresco, L.O. 1993. A decision-support model for monitoring nutrient balances under agricultural land use (NUTMON). *Geoderma* 60, 235-256.
12. Fresco, L.O. and Kroonenberg, S.B. 1992. Time and spatial scales in ecological sustainability. *Land Use Policy* 9, 155-168.
13. Isermann, K. 1993. Territorial, continental and global aspects of C, N, P and S emissions from agricu1tural ecosystems. In: *Interactions of C, N, P and* S *Biochemical Cycles and Global Change.* Wollast, R. (ed.). Springer-Verlag, Berlin, Germany, pp. 79-121.
14. Prudencio, C.Y. 1993. Ring management of soils and crops in the West African semi-arid tropics: The case of the mossi farming system in Burkina Faso. *Agric. Ecos. Envir.* 47, 237-264.
15. Pretty, J.N., Thompson, J. and Kiara, J.K. 1995. Agricultural regeneration in Kenya: the catchment approach to soil and water conservation. *Ambio* 24, 7-15.
16. Tiffen, M., Mortimore, M. and Gichuki, F. 1993. *More People, Less Erosion. Environmental Recovery in Kenya.* John Wiley & Sons, New York, US.
17. Anonymous, 1994. *Feasibility of Phosphate Rock Use as a Capital Investment in Sub- Saharan Africa: Issues and Opportunities.* World Bank Position Paper, Washington, USA.
18. Gerner, H. and Harris, G. 1994. The use and supply of fertilizers in sub-Saharan Africa. In: *The Role of Plant Nutrients for Sustainable Food Crop Production in Sub-Saharan Africa.* Van Reuler, H. and Prins, W.H. (eds). VKP, Leidschendam, The Netherlands, pp. 107-126.
19. Bishop, J. and Allen, J. 1989. *The On-site Costs of Soil Erosion in Mali.* Environment Working Paper No.21, World Bank, Environment Department, Washington DC, USA.
20. Baum, E., Wolff, P. and Zöbisch, M. 1993. *Acceptance of Soil and Water Conservation Strategies and Technologies.* Topics in applied resource management in the tropics. German Institute for tropical and subtropical agricultural research (DITSL), Witzenhausen, Germany.
21. Bojö, J.P. 1991. Economics and land degradation. *Ambio* 20, 75-85.
22. De Graaff, J. 1993. *Soil Conservation and Sustainable Land Use: an Economic Approach.* Royal Tropical Institute, Amsterdam, The Netherlands.
23. Stocking, M.A. 1986. *The Cost of Soil Erosion in Terms of Loss of Three Major Elements.* FAO consultants working paper 3. FAO, Rome, Italy.
24. Ståhl, M. 1993. Land degradation in East Africa. *Ambio* 22, 505-508.

25. The authors are greatly indebted to Bert Janssen, Wageningen Agricultural University, and Frans Makken, Ministry of Foreign Affairs, The Hague, for their oral and written contributions to this paper.
26. First submitted 24 July 1995. Accepted for publication after revision 25 October 1995.

Eric M.A. Smaling, has a PhD in tropical soil science; he is a senior researcher in soil fertility management and nutrient budget studies, and mainly active in sub-Saharan Africa. He is acting head of Department of International Cooperation. His address: DLO Winand Staring Centre for Integrated Land, Soil and Water Research (SC-DLO), P.O. Box 125, 6700 AC Wageningen, The Netherlands.

Louise O. Fresco has a PhD in agronomy and farming systems research and is professor of agronomy, University of Wageningen. Her address: Department of Agronomy, Wageningen Agricultural University, P.O. Box 341,6700 AH Wageningen, The Netherlands.

Andre de Jager has an MSc in agricultural economics in developing countries and is a senior researcher in farm household development economics. His address: DLO Agricultural Economics Research Institute (LEI-DLO), P.O. Box 29703, 2502 LS The Hague, The Netherlands.

Chapter 2 Conceptual framework for analysing nutrient flows and economic performance in smallholder farming systems

De Jager, A., Nandwa, S.M. and Okoth, P.F., 1998.

Monitoring nutrient flows and economic performance in African farming systems (NUTMON). I. Conceptual framework.

Agriculture, Ecosystems and Environment 71: 37-48.

ELSEVIER

Agriculture, Ecosystems and Environment 71 (1998) 37–48

Agriculture Ecosystems & Environment

Monitoring nutrient flows and economic performance in African farming systems (NUTMON) I. Concepts and methodologies

A. De Jager[a,*], S.M. Nandwa[1,b], P.F. Okoth[b]

[a] *Agricultural Economics Research Institute (LEI-DLO), P.O. Box 29703, The Hague, Netherlands*
[b] *Kenya Agricultural Research Institute - National Agricultural Research Laboratories, P.O.Box 14733, Nairobi, Kenya*

Abstract

Nutrient Monitoring (NUTMON) is a multi-disciplinary and multi-scale approach, addressing the problem of soil nutrient depletion, so far mainly in sub-Saharan Africa. It involves and aims, at the various actors influencing soil nutrient management at different levels. A quantitative and qualitative diagnostic phase, to determine nutrient management and economic performance in existing farming systems, is followed by a targeted process of participatory development of Integrated Nutrient Management (INM) technologies and formulation of facilitating policy instruments. Further development of the approach is required through inclusion of social disciplines, extrapolation of results to district and national scale, better estimations of 'difficult-to-quantify' flows and adding policy oriented activities. © 1998 Elsevier Science B.V. All rights reserved.

Keywords: Nutrient monitoring; Sub-Saharan Africa; Multi-disciplinary; Integrated nutrient management; Technology development

1. Introduction

In sub-Saharan Africa (SSA) farm households, developers and policy makers, increasingly recognise soil nutrient depletion, as one of the major constraints to a sustainable agricultural and rural development (Smaling et al., 1996; Smaling, 1993). Farm households are confronted with deteriorating relative price relations between farm outputs and inputs and increased land pressure, resulting in a net exploitation of soil nutrients. Given the socioeconomic environment, farm households have limited options for investments in nutrient-adding or nutrient-saving techniques, which have been developed in many research centres or are known to farmers already. It is obvious that the complex problem of profitable and sustainable nutrient management, requires more than most of the currently on-going, mono-disciplinary, mono-scale and scattered research activities can offer. It is therefore necessary to integrate different relevant disciplines and scales, and at the same time to disentangle the various issues, into a workable set of problem statements, for targeting research and development.

In this paper, the different disciplines and scales that are relevant to the problem of nutrient depletion are described. Thereafter, the concept of NUTMON is presented, which aims at (i) addressing soil nutrient flows and balances, in a multi-disciplinary, multi-scale

*Corresponding author. E-mail: a.dejager@lei.dlo.nl
[1](soil@arcc.or.ke)

0167-8809/98/$ – see front matter © 1998 Elsevier Science B.V. All rights reserved.
PII: S0167-8809(98)00130-3

approach, and at (ii) participative development of INM techniques. Finally NUTMON is compared to alternative approaches also presented in this Special Issue, and an evaluation of its strengths and weaknesses is made.

2. Disentangling a complex problem

2.1. Disciplinary points of departure

Table 1 shows a general framework for the integrative approach, which enables identification of specific activities or knowledge gaps in the individual cells, and addresses relations to other cells and to the overall problem. In the following sections, the biophysical, economic and sociological aspects will be highlighted.

2.1.1. Biophysical input

In SSA, agricultural production systems are very diverse, which is attributed to an array of drivers, including ethno-history and culture, climate, soils and production goals. The factors influencing the level of soil nutrient depletion, are also many and complex: nutrient management, regeneration and plant protection, livestock integration, soil and water conservation, biodiversity, agricultural policies and marketing structures. Nutrient depletion is the result of a net imbalance, between incoming and outgoing nutrients in farm inputs and outputs. Causes are high crop yields accompanied by low, untimely or inefficient application of manure or fertilizer, farm management practices, leading to high levels of leaching and erosion, inefficient recycling of existing nutrients on the farm, decreasing fallow rates, etc. Because many aspects of farm management, influence these processes, there is a need for a 'basket of technology options', addressing the various causes of depletion. One of the main strategies, encompasses INM, which can be defined as the judicious manipulation of nutrient stocks and flows. The primary objective of investigating INM practices, from the biophysical viewpoint, is to identify soil management technologies, that mitigate against nutrient depletion (so that losses are minimized) and those that add nutrients, to the soil-plant systems (as a replenishment strategy) and which are economically viable and socially acceptable. This represents a major shift, from the traditional approach to soil fertility maintenance research, through fertilizer response trials aimed at production per se, in contrast to INM research, seeking more comprehensive solutions toward sustainable production. The objective of INM research, is conducted through monitoring nutrient inflows and outflows, (Table 2) and calculating the balances (OUTPUTS-INPUTS), which helps to quantify the impact of INM practices on soil fertility and hence agricultural production and sustainability (Smaling and Fresco, 1993). The importance and potential contributions of INM, are widely recognized in SSA (Janssen, 1993). However, just as smallholders may not adopt INM consciously, similarly researchers have in the past defined INM narrowly, only in terms of organic and inorganic fertilizers. Experience has shown, that much higher returns to inputs occur, when different nutrient adding technologies are applied, in accompaniment of nutrient saving practices.

2.1.2. Economic input

Decisions concerning soil nutrient management, are taken at the farm household level and are strongly influenced, by short-term economic considerations. Because the majority of the small-scale farmers, have to deal with an insecure climatological and market environment, short-term cost-benefit analysis, can explain a large part of the farm household behaviour (Bishop, 1995). The introduction of structural adjustment policies for instance, drastically changed the value-cost ratio of fertilizer use on maize and millet in West Africa, resulting in decreasing fertilizer consumption (Gerner and Harris, 1994) and more negative nutrient balances. Although the farm households, are often well aware of the short- and long-term effects and have developed or adopted relevant alternative technologies, their options to address this situation, are limited because of factors like poor property rights, immediate cash needs, high risks, shortage of labour, limited infrastructure and insecure agricultural output markets. The long-term economic impacts of soil nutrient depletion, both at farm household and at national level, have proven to be difficult to quantify. Estimation of the future loss of production (Bishop and Allan, 1989; Bojö, 1991; De Graaff, 1993) and calculation of the replacement, costs of the depleted nutrients (Van der Pol, 1992) are the most commonly

Table 1
Multi-disciplinary and multi-scale framework for addressing soil nutrient mining in SSA and major knowledge gaps

Discipline → **Spatial scale ↓**	**A** **Biophysics / Agronomy**	**B** **Economy**	**C** **Sociology / Knowledge systems**	
I. Root zone / Soil-Plant	- Measurement difficult-to-quantify flows - Defining of and description changes in nutrient stocks		- Farmers' learning process of nutrient management	
II. Plot / Farm	- Relation productivity and nutrient mining	- Farm household decision making and perceptions - Trade off economy and sustainability - Environmental-economic analysis	- Farmers' learning and monitoring process - Social characteristics and adoption INM techniques - Participative methods for INM technology development	
III. Village / Community	- Up-scaling farm-level nutrient balances		- Knowledge systems and platforms for INM-technology development	
IV. Catchment / AEZ	- Up-scaling farm-level nutrient balances		- Knowledge systems and platforms for INM-technology development	
V. District / Country	- Up-scaling farm-level nutrient balances - National and international nutrient flows	- Environmental-economic analysis - Policy instruments and INM - Development scenarios	- Perceptions different actors - Conflict of interests between actors	
	---------------- Integration of scales and disciplines -------------------			

applied methods. For example Stocking (1986) calculated, that soil erosion represents a massive hidden cost to the national economy of Zimbabwe. However, in SSA any form of internalisation of such hidden costs in the planning and assessment of national government policies is virtually absent. Inclusion of these hidden costs is essential, to change the socio-economic environments of farm households, to facilitate the large-scale implementation of INM techniques (Smaling et al., 1996).

2.1.3. Sociological input

Changes in farm management practices and adoption of alternative technologies at farm household level are complex processes, which involve more than only technical and economical aspects. Relatively simple packages of technology, for rather homogenous groups of farmers, such as in the Green Revolution, have been widespread using the most familiar transfer of technology approach. However, more complex management changes such as IPM and INM, need

Table 2
Nutrients inputs, outputs and internal flows at the farm and lower levels

Input (IN)	Output (OUT)	Farm and lower levels (Fl)
IN1 Mineral fertilizers	*OUT1 Farm products*	*FL1 External feeds*
	(a) Crop products	(a) Consumption of external feeds
	(b) Animals products	(b) Decay of external feeds
IN2 Organic inputs	*OUT2 Other organic outputs*	*FL2 Household waste*
(a) Feeds	(a) Crop residues	(a) Redistribution of household waste
(b) Organic fertilizers	(b) Manure	(b) Consumption of household waste
(c) External grazing		(c) Decay of household waste
(d) Purchased food		
IN3 Atmospheric deposition	*OUT3 Leaching*	*FL3 Crop residues*
	(a) Soil nutrients	(a) Redistribution of crop residues
	(b) Nutrients from dunghills	(b) Consumption of crop residues
		(c) Decay of crop residues
IN4 Biological N-fixation	*OUT4 Gaseous losses*	*FL4 Grazing of vegetation*
(a) Symbiotic fixation	(a) Soil nutrients	
(b) Non-symbiotic fixation	(b) Nutrients from dunghills	
	(c) Burning of crop residues	
IN5 Sedimentation	*OUT5 Erosion*	*FL5 Animal manure*
(a) Irrigation		(a) Excretion of manure by the animals
(b) Natural flooding		(b) Redistribution of farm yard manure
	OUT6 Human excreta	*FL6 Farm products to the homestead*
		(a) Crops products to the food stock
		(b) Animal products to the food stock
		(c) Consumption of food items

an entirely different approach (Agudelo and Kaimowitz, 1989; Matteson et al., 1994). Farm households' perceptions, creativity and competence are essential elements, which need to be fully exploited for a successful, large-scale implementation of these more complex technologies. Observation, scientific and local indicators, registration of processes and states in maps, diagrams and records, play an important role in this approach and comparison of scientific with farmers' evaluation, are major elements of such an approach. Deugd et al. (1998), elsewhere in the Special Issue, propose a concrete strategy for implementation in INM technology by facilitating farmer learning and innovation.

2.2. *Scalar point of departure*

Agriculture has been described as a hierarchy of nested (agro)ecosystems, that one may trace to a greater complexity and longer time scales, from the crop and animal community upwards, through the farm system to the regional and global system levels (Fresco and Kroonenberg, 1992). At each level, sustainability refers to other variables and boundary conditions and involves different temporal and spatial scales. This essentially means that system levels interact, so that the characteristics of a given system, are boundary conditions at the lower level. Currently five scale levels are distinguished, at which nutrient flows and/or economic performance can be measured (Table 1).

2.2.1. *Country/district*

At the (sub)national level, one may consider the movement of farm produce into and out of the country, but also from one province or district to the other. Such movements translocate the nutrients, such that the recipient district, receives extra nutrients, while the exporting district gets depleted of the same. A thorough analysis at this level, requires data at national level, on the movement of nutrients, in various agricultural sectors, between districts and the economic performance of these agricultural sectors. Agricultural census, national living standard surveys and individual studies, are often the only sources of information, but the fact that this level adresses administrative boundaries, often helps when it comes to collecting basic data. Economic assessment at this level, differs from the levels below, in adjusting for distorted prices and including national social and environmental costs and benefits.

2.2.2. Catchment/AEZ

At the physiographic system levels 'Agro-ecological zone' and 'Catchment', one considers the intra-AEZ and intra-catchment movement of nutrients. Such movements could be occasioned, by the availability of one of the commodities, in one part of the AEZ and its absence in the part to where it is translocated. Economic performance and comparative advantages of agricultural sub-sectors at AEZ level, will largely determine nutrients flows into, out of and between them. At the catchment level, INM practices at the upper slopes, middle slopes and bottomlands are often closely interlinked. In the highlands of Madagascar, for example, farmers do not mind erosion on the upper slopes to be high, as long as it keeps their bottomlands fertile. Moreover, it is more common now than before, to manage catchments jointly. In that sense, 'catchment' has also become a system level with a social bearing.

2.2.3. Village/community

This level relates well to the sociological entry point, with West Africa providing the best examples. Here, farming is largely a community-driven activity, with village elders often in a position to indicate where families should plant their crops. Land ownership, microcredit availability, marketing of products, and the relation to nomadic herdsman who also use the land, make it a highly important spatial and social scale to address INM.

2.2.4. Farm/plot

At the farm level, the nutrients move from one plot to the next, either in the form of green manure, animal manure or crop residues, for the purposes of increasing the fertility of the receiving plots. Feeding of cattle in an enclosure, with grass from a separate plot, is an example of an intra-farm plant nutrient flow or an internal flow. When the grass is obtained from a different farm, it is an inter-farm flow or an external flow. This is the basic scale level, for measuring economic performance of agricultural production. The various enterprises within the farm, compose the total farm income and the farm cash flow. In most regions in SSA, off-farm income, however, forms a major contribution, to the total farm household income and cash income. The decision on nutrient management taken at this level, determines the nutrient flows and balances at higher scales. The farm household, the main actor at this level, integrates agronomic, economic and social objectives, to arrive at specific nutrient management practices. At the plot level, one may consider the internal movement of nutrients from one crop to the other. An example, is the fixation of nitrogen by leguminous plants, later to be used by other crops. These are micro-level nutrient flows, which can only be monitored at the plot level. The enterprise level, is the lowest level of measuring economic performance and broadly coincides with the plot level for nutrient management.

2.2.5. Soil-plant/root zones

The lowest level of measuring nutrient flows, is at the soil-plant system and the root zone. At the lowest level, most movements are controlled by chemical and physical soil processes such as oxidation, pH differences, N-fixation, nutrient mobilization and volatilization, denitrification and the moisture status of the soil. The depletion of nutrients through leaching below the root zone, also falls in this category of nutrient flows. The nutrient flows at this level, could be harmful or beneficial to the crop, depending on whether it is an INPUT or an OUTPUT flow (Table 2). The Soil-plant level, is also the one where nutrient stocks and nutrient flows are integrated, and where nutrient use efficiency is measured.

3. The NUTMON concept

3.1. Introduction

NUTMON aims at the development of a comprehensive multidisciplinary methodology, which is

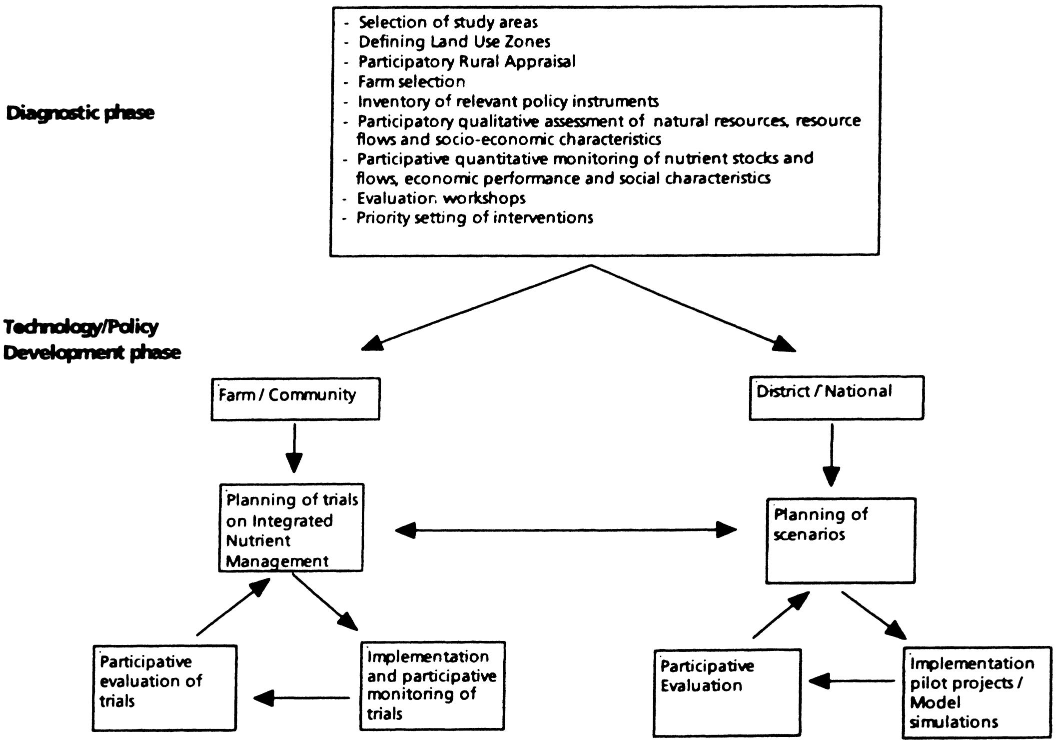


Fig. 1. NUTMON concept.

targeted at the different factors dealing with the management of natural resources in general and plant nutrients in particular. Farm monitoring, takes place at plot and farm household level, because most of the decisions concerning nutrient management are taken at that level. Influences of processes at lower scales (for example, factors determining leaching) and higher scales (policy instruments influencing farm management decisions), are studied as well and incorporated in the farm level approach. In Fig. 1, the NUTMON concept, is summarized in a number of sequential methodological steps.

Two major phases can be distinguished: diagnosis and analysis of existing farm and nutrient management, and participatory INM-technology and policy instrument development. The diagnostic phase aims at analysing the current nutrient management, determining the magnitude and major sources of nutrient depletion, analysing the economic performance, creating farm households' awareness of nutrient management aspects, and jointly with the farm households' arriving at a research and development agenda. The results of this diagnostic phase, are the basis for planning and implementation of on-farm trials, relating to INM and scenario studies concerning policy instruments, to facilitate adoption at farm household level. Farmers, extensionists, NGO-staff, researchers and policy makers are fully involved in this planning and implementation process and therefore both existing indigenous and science-generated knowledge, (or a combination of the two), can be incorporated in this process of technology development. The sequential steps of the diagnostic phase, were applied in the NUTMON pilot project in Kenya (Van den Bosch et al., 1998b; De Jager et al., 1998), and are discussed in more detail hereafter. However, some aspects of the concept, such as inventory of policy instruments and participatory soil and nutrient flow mapping, have only recently been implemented, in on-going field projects and are therefore described in more global terms. This also applies to the methodology for INM technology and policy development phase.

3.2. Diagnostic phase

3.2.1. Selection of study areas, defining LUZ and farm selection

Study districts are selected according to priorities set by broad government policies, donor demands, agro-ecological settings or according to available research infrastructure or resources. To classify the complex and heterogeneous situation at district scale, various land use zones (LUZ) are identified. For this process research staff and resource persons use the following tools: (i) geographical maps; (ii) agro-ecological zone maps according to Jaetzold and Schmidt (1982); (iii) land use maps of the district; (iv) recent satellite images and air photos to adjust boundaries of the major land use zones; (v) secondary information collected within the district on crops and livestock diversity and distribution; and (vi) participatory rural appraisal (PRA) including transect walks and drives by multidisciplinary teams of researchers and extension staff.

The LUZ, are further disaggregated into smaller units, according to the farm types occurring in the zone. The farm types are differentiated according to: (i) topography, (ii) sizes, (iii) production level, (iv) management level, (v) level of input use, (vi) the level of resource endowment and (vii) socio-economic characteristics. PRA is the main tool used for the identification, of these different farm types and its major constraints in farm management. Depending on the type of study, the objectives and available resources, different sampling procedures can be applied to select a representative sample of individual farms to participate in the monitoring process. Especially when up-scaling of field level results is intended, ample attention needs to be paid to the sampling procedure and sampling size. Hereafter, the participating farms are further fragmented, into plots and enterprises for the determination of nutrient flows (Van den Bosch et al., 1998b). Table 3 presents an example of the result of this exercise for the Embu District in Kenya. This district stretches all the way from the top of Mount Kenya to the semi-arid footslopes to the east.

3.2.2. Inventory of relevant policy instruments

Based upon interviews with policy makers and review of national general and agricultural policy documents, an overview of existing policy instruments affecting farm management practices and soil nutrient management is made. Interviews and discussions with district level policy makers, private sector representatives and farm households provide a global, mostly qualitative insight into the impact and effectiveness of these policy instruments.

3.2.3. Participative qualitative assessment of natural resource flows and socioeconomic characteristics

Before the quantitative monitoring exercise, farm households are involved in a participatory process, to characterise their current farm nutrient management and economic performance. Together with the farm household members, maps of the farms are drawn indicating soil characteristics, nutrient flows and economic flows. Through these exercises, discussions with farm households on aspects of soil nutrient management are started and the awareness of ongoing processes is facilitated. In a discussion session with farm households, the results of the quantitative monitoring exercise, are compared with this qualitative information.

3.2.4. Quantification of nutrient stocks

The soil nutrient stock of a farm is defined as the total amount of nutrients present in the top 30 cm of the soil profile. Both nutrients in the organic matter fraction, nutrients absorbed to the solid phase and dissolved nutrients are regarded as part of the stock. Between 10 and 25 samples per farm are taken, depending on the farm size and heterogeneity of soils and cropping pattern.

3.2.5. Participative quantitative farm inventory and monitoring of nutrient stocks, flows and economic performance and social characteristics

Primary data are collected during structured interviews with one or more members of the farm household. The questionnaire consists of two major sections:

- farm inventory, identifying the major features of the farm and serving as a framework for the monitoring phase;
- monitoring, identifying and quantifying the flows to and from all farm units; all relevant nutrient and

Table 3
Descriptions of defined farm types and LUZ in Embu district, Kenya

Land use zone (LUZ)		Farm type
Name	Tea/dairy	1. Farmer raising grade dairy cows in a conventional zero-grazing unit.
Altitude	1770–2070 m	2. Farmer grazing grade dairy cows on natural pastures and feeding napier grass in the night boma.
Mean temperature	15.8–17.7°C	3. Tethering of cross-bred cows within homestead compound, roadside pastures, etc.
Annual rainfall	1750–2000 mm	
Main soil types	Andosols	
Name	Tea/coffee/dairy	1. Farmer zero-grazing grade dairy cows, with a high level of fertilizer and manure input in the farm.
Altitude	1590–1830 m	2. Farmer free grazing cross-bred dairy cows (within own farm), with medium level of fertilizer and manure input on the farm.
Mean temperature	17.5–18.9°C	3. Farmer free grazing cross-bred cows within own farm. Low levels of manure and fertilizer applied on crops.
Annual rainfall	1400–1800 mm	
Main soil types	Nitosols, andosols	
Name	Coffee/maize	1. 70% of the farmer's land under coffee and 30% under maize and other food crops. The farmer has a conventional zero-grazing unit containing grade cattle.
Altitude	1280–1830 m	2. 50% of the farmer's land under coffee and 50% under maize and other food crops. The farmer is practicing semi-zero grazing using cross-breed cattle.
Mean temperature	18.9–20.7°C	3. 30% of the farmer's land under coffee and 70% under maize and other food crops. The farmer is practicing zero grazing mainly feeding crop by-products and rresidues to zebu cattle.
Annual rainfall	960–1500 mm	
Main soil types	Nitosols, cambisols ferralsols	
Name	Tobacco/food crops	1. Semi-zero grazing farmer. Animals grazing within his piece of land and sleep at home in a boma.
Altitude	980–1220 m	2. Controlled grazing farmer. Animals grazing within his piece of land and sleep in a boma at home.
Mean temperature	20.7–22.5°C	3. Farmer with no cattle.
Annual rainfall	780–1100 mm	
Main soil types	Ferralsols, acrisols	
Name	Livestock/shifting cultivation	1. Farmer with a homestead garden where he/she is applying manure. The farmer also has another shamba (either owned or borrowed) where there is no application of manure.
Altitude	830–1130 m	2. Application of manure on homestead garden only. Farmer has no other external garden.
Mean temperature	17.5–18.9°C	3. No homestead garden. There is an external garden where there is no application of manure.
Annual rainfall	700–900 mm	
Main soil types	Ferralsols, acrisols	

economic flows are traced, including their sources and destinations.

The inventory is conducted at the start and end of each monitoring year. Monitoring usually takes place each month but may also have a lower intensity if farming systems are not too complex or if areas have only one major growing season. Table 4 summarises the different types of information gathered. Apart from the information obtained from farm monitoring,

Table 4
Main information categories included in the questionnaire

Information group	Type of information
Farm Inventory	
General farm data	Geographical situation, land ownership etc
Demographic structure of the household	Identification of all persons at the farm, sex, age and occupation
Primary production units	Identification of parcels and parcel sizes
Secondary production units	Identification of animal groups
Sketch of the farm	Sketch of parcels and farm infrastructure
Other units	Identification of garbage heaps, compost pits, dunghills and kraals
Implements and machinery	Identification of implements present on farm; number and age
Input – output monitoring	
Primary production units	Identification of the plots and crops present at the time of monitoring
Input in primary production units	Quantity and source of fertilizers, seeds, manure, crop residues, feeds, pesticides, labour, traction etc
Inputs in secondary production units	Quantity and source of fodder, concentrates, veterinary services, labour, etc
Output primary production units	Quantity and destination of harvested products and crop residues
Output secondary production units	Quantity and destination of milk, eggs, hides, skins, hiring out of animals, traction
Average confinement of the animals	Confinement to fields, pastures, fallows, farm yards, kraals and outside the farm
Redistribution of manure and household waste	Quantity and destination of reused manure and household waste
Growth of herd	Number of animals born, purchased, gifts, consumed, died
Inputs and outputs food stock	Bookkeeping of staple food in stock
Family labour	For each person: number of days spent on crops, livestock, general farm, household, off-farm activities
Off-farm income	Estimated off-farm income and amount invested in farm activities

Source: Van den Bosch et al., 1998a.

additional secondary information is collected to enable the calculation of nutrient and economic flows, such as nutrient contents of plant, animal products, manure and compost, prices of inputs and outputs etc. Reference is made to Van den Bosch et al. (1998a) for a comprehensive description of the type of collected data and nutrient flows and balances calculation methods.

3.2.6. Evaluation workshops and priority setting

The results of calculation exercise are discussed and validated in a workshop between the participating farm households, extensionists and research staff. This participative diagnosis is then followed by discussions focusing on formulating priorities for testing and developing INM-technologies in the different farm types and LUZ.

3.3. Participatory INM-technology development

The combination of quantitative nutrient flows and balances, economic performance indicators and farmers' perceptions, determines which are the most appropriate technologies for a specific farming system. The results of the diagnostic phase and especially of the participative priority setting procedure form the point of departure for the INM technology development. The proposed approach combines traditional farming systems approaches (Norman and Collinson, 1986; Tripp and Woolley, 1989), with more recently developed participatory technology development (PTD) and farmers' learning concepts (Chambers et al., 1989; Reijntjes et al., 1992). In the planning stage, farm households, extension staff and researchers determine if any existing indigenous or science-based nutrient saving or nutrient adding technology, is available to address the prioritised problem. For existing techniques on-farm trials are planned and implemented by farmers, to test and adapt these techniques in a participatory learning process. At the same time, suggestions for on-station trials, may be done for testing new ideas or not yet very well developed technologies. A combined and interactive farmer-based and science-based monitoring and evaluation are implemented using existing PTD tools, qualitative nutrient flow diagrams and the NUTTOOL (Van den

Bosch et al., 1998a), i.e., the software on NUTMON that is presently developed into a decision-support tool. The planning of a new cycle of experiments depends upon the results of monitoring of the trials and the learning process of the farm households (Fig. 1).

3.4. Development of facilitating policy instruments

Because policy instruments and its implementation directly or indirectly affect farm management decision making and adoption of alternative technologies (Holden and Shanmugaratnam, 1995; Lutz,

Table 5
Summary of methodological aspects of nutrient balance studies presented in this volume

Author(s)	Title	Disciplines (A/E/S)	Scale level (I–V)	Nutrient balance, calculation method	Macro-micro nutrients etc.	Balances related to stocks	Farmers' perceptions	Policy level results
Brand and Pfund	Site- and watershed-level assessment of nutrient dynamics under shifting cultivation in Eastern Madagascar	A	II, IV	FB	C, N, P, K, Ca, Mg	No	No	No
Folmer et al.	Assessment of soil fertility depletion in Mozambique	A	V	FB	N,P	Yes	No	No
Elias et al.	Nitrogen and phosphorus balances of Kindo Koisha farms in southern Ethiopia	A, E	II	FB	N,P	No	No	No
Brouwer and Powel	Increasing nutrient use efficiency in West-African agriculture: impact of micro-topography on leaching from cattle and sheep manure	A	I, II	PB	N, P	No	No	No
Baijukya and De Steenh, P.	Nutrient balances and their consequences in the banana-based land use systems of Bukoba District, North-West Tanzania	A	II	FB	N, P, K, Ca, Mg, S	No	No	No
Wortmann and Kaizzi	Nutrient balances and expected effects of alternative practices in farming systems of Uganda	A	II	FB	N, P, K	No	No	No
Harris	Farm-level assessment of the nutrient balance in Northern Nigeria	A	II	PB	N, P, K, Ca, Mg	No	No	No
Shepherd and Soule	Soil fertility management in West Kenya: dynamic simulation of productivity, profitability and sustainability at different resource endowment levels	A, E	I, II	FB	C, N, P, K	Yes	No	No
Defoer et al.	Participatory action research and quantitative analysis for nutrient management in Southern Mali: a fruitful marriage?	A	II, III	PB	N, P, K	No	Yes	No
	NUTMON	A, E	II	FB	N, P, K	Yes	Yes	No

A–Agronomy; I–Soil-plant; E–Economy; S–Sociology; FB–Full balance; PB–Partial balance.
III-Plot-farm; III–Village-community; IV–Catchment-AEZ; V–District-country.

1992; Barrett, 1991), alternative policy instruments which facilitate adoption of INM technology are developed. In workshops with relevant policy makers, alternative policy instruments are discussed and formulated. Testing the impact of these policies is done through pilot projects (for instruments such as credit schemes, input procurement, marketing systems etc.), simple model simulations and stakeholders interviews (for price and market interventions). For the identified INM technologies, recommended policy instruments to facilitate adoption at a wide scale, are formulated and discussed with relevant stakeholders.

4. Evaluation of strengths and weaknesses

Apart from the above described approach, a number of other methodologies and case studies to address soil nutrient depletion and study nutrient flows and nutrient balances are presented in this Special Issue. In Table 5 these papers have been classified according to major methodological foci, and are compared to the NUTMON approach. It appears, that the majority of the approaches encompass agronomic plot and farm level studies. Only in a few cases are economic issues included and sociological aspects are virtually absent. No concrete examples of up-scaling plot and farm field level studies to higher scales have been presented. Most of the methodologies, make use of a mix of primary and secondary data to calculate either full or partial balances (not all the nutrient flows taken into account). Apart from the macro-nutrients N, P, and K some approaches include also Ca, Mg and C in the balance studies. None of the field level study approaches resulted into concrete policy level recommendations. As compared to the others, NUTMON seems the most comprehensive. However, further improvement of the approach is required through inclusion of social disciplines and farmers' learning processes, extrapolation of results to district and national scale, better estimations of 'difficult-to-quantify' flows and adding policy oriented activities. These, and other observed knowledge gaps as presented earlier in the general framework (Table 1), will receive priority in the further development of the methodology and during field level implementation.

References

Agudelo, L.A., Kaimowitz, D., 1989. Institutional linkages for different types of agricultural technologies: rice in the Eastern plains of Colombia. Linkage discussion paper 1, ISNAR/RTTL.

Barrett, S., 1991. Optimal soil conservation and the reform of agricultural pricing policies. J. Develop. Econom. 36, 167–187.

Bishop, J., Allan, J., 1989. The on-site costs of soil erosion in Mali. Environment working paper No. 21, Worldbank, Washington, DC.

Bishop, J., 1995. The economics of soil degradation: an illustration of the change in productivity approach to valuation in Mali and Malawi. IIED/Environmental Economics Programme. LEEC Paper DP 95-02, London.

Bojö, J.P., 1991. Economics and land degradation. Ambio 20, 75–85.

Chambers, R., Pacey, A., Thrupp, L.A., 1989. Farmer first: farmer innovation and agricultural research. Intermediate Technology Publications, London, UK.

De Jager, A., Kariuki, I., Matiri, F.M., Odendo, M., Wanyama, J.M., 1998. Monitoring nutrient flows and economic performance in African farming systems (NUTMON). IV. Linking farm economic performance and nutrient balnaces in three districts in Kenya. Agric. Ecosyst. Environ. 71, 83–94.

De Graaff, J., 1993. Soil conservation and sustainable land use: an economic approach. Royal Tropical Institute, Amsterdam, Netherlands.

Deugd, M., Röling, N., Smaling, E.M.A., 1998. A new praxeology for integrated nutrient management: facilitating innovation with and by farmers. Agric. Ecosyst. Environ. 71, 271–285.

Fresco, L.O., Kroonenberg, S.B., 1992. Time and spatial scales in ecological sustainability. Land Use Policy 9, 155–168.

Gerner, H., Harris, G., 1994. The use and supply of fertilizers in sub-Saharan Africa. In: The role of plant nutrients for sustainable food crop production in sub-Saharan Africa, In: Van Reuler, H., Prins, W.H. (Eds.), VKP, Leidschendam, Netherlands.

Holden, S.T., Shanmugaratnam, N., 1995. Structural adjustment, production subsidies and sustainable land use. Forum Develop. Studies 2, 247–266.

Jaetzold, R., Schmidt, H., 1982. Farm management handbook of Kenya. Vol II (Natural conditions and farm management information). Ministry of Agriculture, Kenya.

Janssen, B.H., 1993. Integrated nutrient management: the use of organic and mineral fertilizers. In: Van Reuler, H., Prins, W.H. (Eds.) The role of plant nutrients for sustainable food crop production in sub-Saharan Africa. VKP, Leidschendam, Netherlands.

Lutz, E., 1992. Agricultural trade liberalization, price changes and environmental effect. Environ. Resource Econom. 2, 79–89.

Matteson, P.C., Gallagher, K.D., Kenmore, P.E., 1994. Extension of integrated pest management for plant hoppers in Asian irrigated rice: empowering the user. In: Denno, R.F., Perfect, T.J. (Eds.) Ecology and management of plant hoppers. Chapman and Hall, London.

Norman, D.W., Collinson, M., 1986. Farming systems research in theory and practice. In: Remenyi, J. (Ed) Agricultural systems research for developing countries, ACIAR Proc. No. 11. Australian Council for International Agricultural Research, Canberra, Australia.

Smaling, E.M.A., 1993. Soil nutrient depletion in sub-Saharan Africa. In: Van Reuler, H., Prins, W.H. (Eds.) The role of plant nutrients for sustainable food crop production in sub-Saharan Africa. pp. 53–67.

Smaling, E.M.A., Fresco, L.O., 1993. A decision-support model for monitoring nutrient balances under agricultural land use (NUTMON). Geoderma 60, 235–256.

Smaling, E.M.A., Fresco, L.O., DeJager, A., 1996. Classifying, monitoring and improving soil nutrient stocks and flows in African agriculture. Ambio 25, 492–496.

Stocking, M.A., 1986. The cost of soil erosion in terms of loss of three major elements. FAO consultants working paper 3. FAO, Rome, Italy.

Reijntjes, C., Haverkort, B., Waters-Bayer, A., 1992. Farming For The Future: An Introduction To Low-External-Input And Sustainable Agriculture. Macmillan, ILEIA, Leusden.

Tripp, R., Woolley, J., 1989. The planning stage of on–farm research: identifying factors for experimentation. CIMMYT and CIAT, Mexico DF and Cali, Colombia.

Van den Bosch, H., De Jager, A., Vlaming, J., 1998a. Monitoring nutrient flows and economic performance in African farming systems (NUTMON) II. Tool development. Agirc. Ecosyst. Environ. 71, 54–64.

Van den Bosch, H., Maobe, S., Ogaro, V.N., Gitari, J.N., Vlaming, J., 1998b. Monitoring nutrient flows and economic performance in African farming systems (NUTMON). III. Monitoring nutrient flows and balances in three districts in Kenya. Agric. Ecosyst. Environ. 71, 65–82.

Van der Pol, F., 1992. Soil mining: an unseen contribution to farm income in Southern Mali. KIT Bulletin No. 325, Royal Tropical Institute (KIT), Amsterdam, Netherlands.

Chapter 3 Description of the NUTMON tool

Bosch, H. van den, De Jager, A. and Vlaming, J., 1998.

Monitoring nutrient flows and economic performance in African farming systems (NUTMON). II. Tool development.

Agriculture, Ecosystems and Environment 71: 49-62.

ELSEVIER

Agriculture, Ecosystems and Environment 71 (1998) 49–62

Agriculture Ecosystems & Environment

Monitoring nutrient flows and economic performance in African farming systems (NUTMON) II. Tool development

H. Van den Bosch[a,*], A. De Jager[b], J. Vlaming[a]

[a] Winand Staring Centre for Integrated Land, Soil and Water Research (SC-DLO), P.O. Box 125, NL-6700 AC, Wageningen, Netherlands
[b] Agricultural Economics Research Institute (LEI-DLO), P.O. Box 29703, NL-2502 LS, Hague, Netherlands

Abstract

Farm-NUTMON is a research tool that integrates the assessment of stocks and flows of the macro-nutrients nitrogen, phosphorus and potassium on the one hand and economic farm analysis on the other. The tool is applicable at both the farm and the activity level. It includes a structured questionnaire, a database, and two simple static models (NUTCAL for calculation of nutrient flows and the ECCAL for calculation of economic parameters). Finally, a user interface facilitates data entry, data manipulation and extracts data from the database to produce input for both models. Farm-NUTMON allows (i) estimation of the extent to which farmers generate income from soil nutrient mining, (ii) assessment of the impact of changes in farm management techniques on nutrient balance and economic performance at activity level and farm level, and (iii) calculation of the economic impact of exogenous changes on the farm and activity level. © 1998 Elsevier Science B.V. All rights reserved.

Keywords: Kenya; Nutrient balance; Integrated nutrient management; Economic performance indicators; Modelling

1. Introduction

In sub-Saharan Africa (SSA) it seems that crop production progresses at the expense of sustainable land use. Farmers are primarily concerned about crop and animal production, for the forthcoming season. Long-term processes that adversely affect sustainability, such as decrease of soil nutrient stocks, are less visible and may therefore receive a lower priority at farm level. By soil fertility management, the farmer manipulates flows of nutrients into, out of and within the farm. Soil fertility management takes place at farm level, and at the level of farm activities such as crop and livestock activities, since decisions are taken by individual farm households or by groups of households at community level. Decisions concerning soil fertility management, are determined by the household objectives on the one hand and the available resources and the socioeconomic environment on the other hand. Households objectives consist of a mixture of identifiable objectives, such as food security, profit or cash maximization, risk aversion, and long term security of livelihood. Available resources are labour, cash, implements and the natural resources, such as water availability and actual soil fertility.

*Corresponding author. Tel.: +31-317-474479; fax: +31-317-424182; e-mail: h.vandenbosch@sc.dlo.nl

0167-8809/98/$ – see front matter © 1998 Elsevier Science B.V. All rights reserved.
PII: S0167-8809(98)00131-5

Integrated nutrient management (INM) is the judicious manipulation, of nutrient stocks and flows aiming at maintaining soil fertility and sustaining production at the same time. Monitoring of nutrient stocks and flows, is a tool for assessing the degree of nutrient mining in an agro-ecosystem. When applied to systems where INM practices are being introduced, nutrient monitoring can be used to assess the effects of INM strategies on soil nutrient stocks and flows.

A quantitative nutrient balance model (NUTBAL) for calculating inputs and outputs of nitrogen, phosphorus and potassium in African land use systems, was developed and applied on supra-national scale (Stoorvogel et al., 1993) and district scale (Smaling et al., 1993). Calculating inputs and outputs led to the conclusion that there are considerable net fertility losses in each growing period. NUTBAL was elaborated into a decision-support model (NUTMON), to monitor the effects of changing land use (Smaling and Fresco, 1993). The concept is based on five inputs (mineral fertilizer, organic manure, atmospheric deposition, biological N-fixation, sedimentation) and five outputs (harvested products, crop residues, leaching, gaseous losses and erosion) and is basically scale-independent.

For the application of the NUTMON concept at farm and activity level (activity is defined as the major farm enterprises: annual crops, perennial crops, pastures, fallows, farm yards and livestock), it was deemed necessary, to develop a methodology capable of integrating the two levels. Furthermore, an economic analysis tool was included in order to allow nutrient mining, to be related to the economic performance of the farm. This enables one to estimate the extent to which farmers generate income from soil nutrient mining. The integration of economic and biophysical analysis also makes it possible to evaluate the economic, financial and labour related possibilities and constraints of adoption and implementation of alternative integrated nutrient management strategies, aiming at a more efficient nutrient use. In addition, the impacts of exogenous influences, such as changes in prices of inputs and outputs can be assessed.

For this purpose Farm-NUTMON is introduced in this paper. It is a tool that encompasses different stages in farm analysis: data gathering, data storage and checking, data manipulation (in this case calculation of nutrient stocks and flows and calculation of economic performance parameters) and presentation of the results.

During monthly farm visits information is gathered through discussions with the farm household by means of structured questionnaires. Next, the information thus obtained is entered into a database with a structure similar to that of the questionnaire. Tools that allow viewing and editing of the database have been developed for data checking. These tools, also make it possible, to relate different types of data to each other allowing internal consistency checking. Once checked and corrected, the data can be extracted from the database and transferred into input files for the two models. The input files are used in NUTCAL, to calculate nutrient balances, for all the units identified within the farm and for the farm as a whole. NUTCAL results, are combined with input files from the database and are used in ECCAL, for the calculation of the economic performance indicators.

Farm-NUTMON was applied in a research project evaluating soil fertility management and economic performance at 26 farms, in different Kenyan agro-ecosystems. A land use zonation (LUZ), was carried out in four districts in Kenya. Based on the LUZ's and participatory rural appraisals (PRA), farms were selected with varying agro-ecology and farm management. A detailed description of the methodology of farm selection is presented by De Jager et al. (1998a). Results of the implementation of Farm-NUTMON can be found in Van den Bosch et al. (1998) and De Jager et al. (1998b).

2. Data gathering

2.1. Farm-NUTMON

Farm-NUTMON includes a structured questionnaire, a database, and two simple static models (NUTCAL for calculation of nutrient flows and the ECCAL for calculation of economic parameters). Finally, a user-interface facilitates data entry and manipulation and extraction of data from the database to produce input for both models (Fig. 1). The tool calculates flows and balances of the macro-nutrients N, P and K, and is based on a set of five inflows (mineral fertilizer, organic inputs, atmospheric deposition, biological nitrogen fixation, sedimentation), six outflows (farm

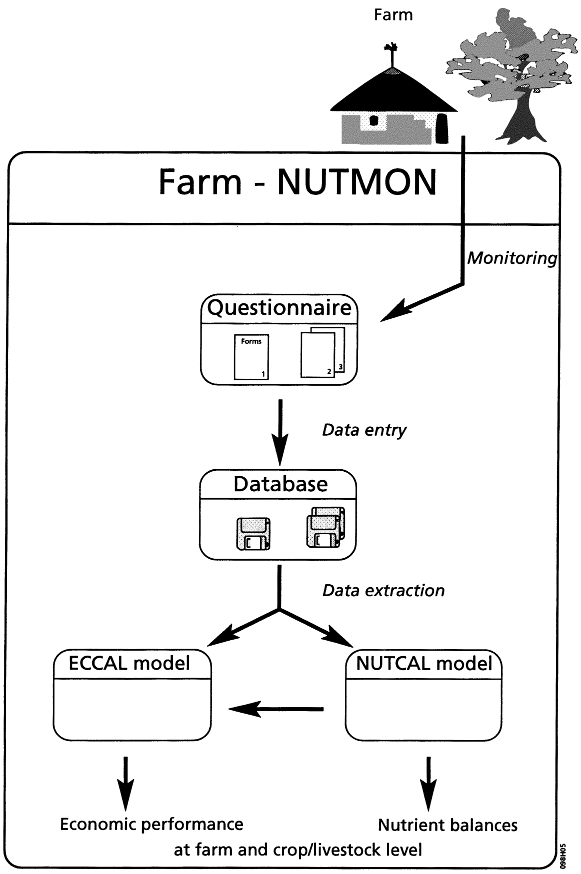


Fig. 1. Schematic representation of farm-NUTMON.

products, other organic outputs, leaching, gaseous losses, erosion and human excreta), and six internal flows (consumption of external feeds, household waste, crop residues, grazing, animal manure, and home consumption of farm products). Fig. 2 shows these flows.

2.2. Questionnaire

The questionnaire is a structured guide used to gather and record information during an interview with one or more members of the farm household. The information asked for is a mixture of biophysical and economic data and relates to both the nutrient and cash flows, as well as to the characteristics of the household. The questionnaire consists of two sections:

1. A farm inventory identifying the major features of the farm and serving as a framework for the monitoring phase;
2. A monitoring part identifying and quantifying the flows to and from all farm compartments. All relevant nutrient and economic flows are traced including their sources and destinations.

The inventory is made at the start and end of each monitoring year. Monitoring usually takes place each month but may also have a lower intensity, if farming systems are not too complex or if areas have only one major growing season. Table 1 summarises the design of the questionnaires.

2.3. Additional information

Apart from the information obtained from farm monitoring, additional information is needed for the calculation of nutrient and economic flows. Table 2 gives an overview, of the additional data required by the calculation models. Values are often site-specific and will require specific market surveys, laboratory measurement and sessions with experts from the districts. Alternatively, information can be gathered from the literature.

3. NUTCAL used for the quantification of nutrient flows

3.1. Farm concept

For the development of NUTCAL the multi-scale concept of NUTMON (Smaling and Fresco, 1993), was tailored for application at both farm and activity level. A detailed conceptual framework was defined: Fig. 2(a) (farm compartments and inflows and outflows) and Fig. 2(b) (farm compartments and internal flows). The definition of compartments within the farm allows analysis of crop and livestock activities in terms of nutrient flows. Within this farm concept, three types of compartments are defined: primary production compartments, secondary production compartments and homestead. The side boundaries of the farm coincide with the physical borders of the farm. Animals temporarily grazed outside the farm are still considered to be part of the farm. The upper boundary

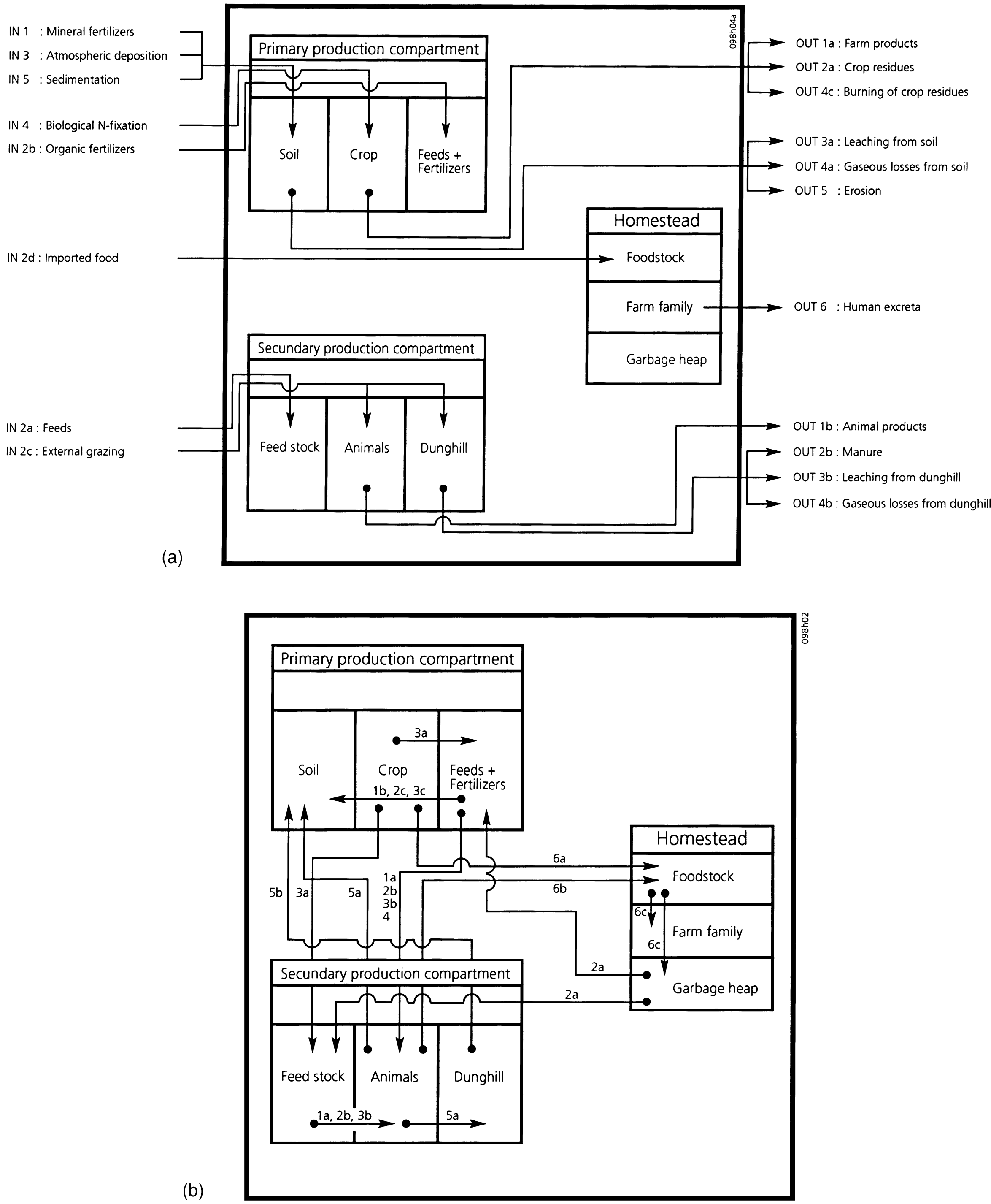


Fig. 2. (a) Farm concept with its compartments, subcompartments and nutrient flows into and out of the farm. (b) Farm concept with compartments, subcompartments and internal flows.

Table 1
Main information categories included in the questionnaire

Information group	Type of information
Farm Inventory	
General farm data	Geographical situation, land ownership etc.
Demographic structure of the household	Identification of all persons at the farm, sex, age and occupation
Primary production compartments	Identification of parcels and parcel sizes
Secondary production compartments	Identification of animal groups
Sketch of the farm	Sketch of parcels and farm infrastructure
Other compartments	Identification of garbage heaps, compost pits, dunghills and kraals
Implements and machinery	Identification of implements present on farm; number and age
Input-output monitoring	
Primary production compartments	Identification of the fields and crops present at the time of monitoring
Input in primary production compartments	Quantity and source of fertilizers, seeds, manure, crop residues, feeds, pesticides, labour, traction etc.
Inputs in secondary production compartments	Quantity and source of fodder, concentrates, veterinary services, labour, etc
Output primary production compartments	Quantity and destination of harvested products and crop residues
Output secondary production compartments	Quantity and destination of milk, eggs, hides, skins, hiring out of animals, traction
Average confinement of the animals	Confinement to fields, pastures, fallows, farm yards, kraals and outside the farm
Redistribution of manure and household waste	Quantity and destination of reused manure and household waste
Growth of herd	Number of animals born, purchased, gifts, consumed, died
Inputs and outputs foodstock	Bookkeeping of staple food in stock
Family labour	For each person: no. of days spent on crops, livestock, general farm, household, off-farm activities
Off-farm income	Estimated off-farm income and amount invested in farm activities

of the farm is the atmosphere-soil or the atmosphere-plant interface, whereas the lower boundary of the farm is defined at 30 cm below the soil surface, because crops usually retrieve the majority of the required nutrients from this layer. Three types of nutrient flows are distinguished: flows into the farm, flows out of the farm, and flows within a farm, (between compartments and subcompartments). Only processes that occur at farm level, compartment level, or subcompartment level, are taken into account. Processes at a lower level (e.g. soil solution level), or a higher level (district level, national level), are not considered.

The primary production compartment (Fig. 2(a)), is defined as a field with various possible activities, such as crops production (annual or perennial), pasture (annual or year-round), fallow and the farm yard. In case of crop production, a mixture of up to three crops is allowed. The primary production compartment has three subcompartments.

1. The ‘soil’ subcompartment is defined as the upper 30 cm of the soil pedon.
2. The ‘crop’ subcompartment is defined as the biomass present, in the above-ground crop parts (both crop products and crop residues).
3. The ‘feeds and fertilizers’ subcompartment, is defined as the total of organic materials on the land, available as feed or as organic fertilizer. In the case of ‘fallow’, ’pasture’, or ’farm yard’ activities, it is assumed that the vegetation is available for animal consumption. This local vegetation is also part of the feeds and fertilizer subcompartment. If the activity is a crop, this grass vegetation, is assumed not to be absent.

For the delineation of the secondary production compartments (Fig. 2(a)), the animals within a farm, are divided into groups. The animals are considered, to be a group if (i) they are all of the same species, and (ii) they are managed as a group by the farmer in terms of feeding and confinement. The secondary production compartment has three subcompartments.

1. The ‘animals’ subcompartment is defined as the group of animals within a secondary production system.

Table 2
Additional data required for farm-NUTMON

Parameter	Unit	Remarks
Crops and crop products		
N, P and K content	(g kg^{-1})	Of crop products and crop residues
Unit price	(local currency)	Of crop products and crop residues
N-fixation	(%)	Of total N uptake by plant
fraction garbage	(%)	Of harvested product
Livestock and livestock products		
Feed requirement	(kg $head^{-1}$ day^{-1})	kg dry matter
Feed conversion fraction	(%)	N, P, K, bulk
N, P and K content	(g kg^{-1})	Of meat and milk products
Unit price	(local currency)	Of meat and milk products
Return percentage	(%)	Fraction of total manure production deposited within farm
External inputs		
N, P and K content	(g kg^{-1})	
Soils and climate		
total N content	(g kg^{-1})	
mineralisation rate	(g kg^{-1} yr^{-1})	
total P content	(g kg^{-1})	
total K content	(g kg^{-1})	
exchangeable K	(meq $100g^{-1}$)	
clay content	(%)	
bulkdensity	(kg m^{-3})	
yearly precipitation	(mm yr^{-1})	Average yearly precipitation
Measurement units		
SI quantity per local unit	SI-unit (kg)	Quantity represented by locally used units

2. The ‘dunghill’ subcompartment is defined as the amount of dung within the corral and/or the dunghill closely related to the corral.
3. The ‘feed stock’ subcompartment is the sum of all feeds routed towards this compartment.

The homestead consists of the following subcompartments.

- The ‘food stock’ subcompartment can be either replenished by food items purchased outside the farm or by crop products and livestock products (meat and milk) from within the farm. It is assumed, that all food items in stock, are consumed by the family within the same monitoring period.
- The members of the ‘farm family’ subcompartment, consume food from the food stock. Part of the food, contributes to body weight and energy production while the remainder is excreted.
- The garbage in the ‘garbage heap’ subcompartment, originates from consumption of food (purchased food, harvested products, meat and milk), by the farm family and is calculated using a crop-specific waste percentage.

3.2. Approaches to quantifying flows

The nutrient balances at the farm and compartment level, are quantified by distinguishing five flows into the farm (IN 1–5), six flows out of the farm (OUT 1–6) and six internal flows (Fl 1–6). Flows into the farm originate outside the farm and have one of the subcompartments within the farm as their destination. Flows out of the farm, are flows from one of the subcompartments to a destination outside the farm. Internal flows are flows from one subcompartment into another subcompartment either within the same compartment or between two compartments. Fig. 2(a) gives an overview of the flows, at farm level as considered in NUTCAL. Basically, three methods are used to quantify the nutrient flows: (1) asking the farmer, (2) use of transfer function and (3) other approaches using sub-models and assumptions.

3.2.1. Method 1: asking the farmer

This method, based on information from the questionnaire, is used for the flows IN 1, IN 2 a, b, d, OUT 1, OUT 2, Fl 2a, Fl 3a, Fl 5b and Fl 6. The farmer usually quantifies the product flow in local compartments that are converted into SI-units by means of conversion factors. Absolute amounts of nitrogen, phosphorus and potassium in the flow are calculated using the nutrient contents of the nutrient carrier.

3.2.2. Method 2: use of transfer functions

Transfer functions are used to estimate those nutrient flows for which the information can not be given by the farmer or be obtained by simple measurements. They are therefore, used to estimate flows IN 3, IN 4, OUT 3, OUT 4 and OUT 5. Transfer functions are simple relations, that explain difficult-to-quantify variables, as a function of easily obtainable parameters such as mean annual precipitation and clay content of the soil. The functions are derived by curve-fitting using data, gathered from the literature. The choice of the functions is mainly based on work by Stoorvogel and Smaling (1990), and Smaling et al. (1993) who performed nutrient balance studies for sub-Saharan Africa and the Kisii district (Kenya).

Wet and dry atmospheric deposition (IN 3), is calculated using a transfer function, derived from literature data (Stoorvogel and Smaling, 1990), linking the nutrient input with the mean annual rainfall

$$\mathrm{IN}\,3_{\mathrm{N}} = 0.14p^{1/2}$$

$$\mathrm{IN}\,3_{\mathrm{P}} = 0.023p^{1/2}$$

$$\mathrm{IN}\,3_{\mathrm{K}} = 0.092p^{1/2}$$

in which IN 3_{N}, IN 3_{P}, IN 3_{K} is the input of N, P and K (kg ha^{-1}yr^{-1}) and p is the mean annual precipitation (mm yr^{-1}). Non-symbiotic N-fixation (IN 4b) is calculated using the following transfer function (Stoorvogel and Smaling, 1990).

$$\mathrm{IN4}_{\mathrm{N}} = 2 + (p - 1350) \times 0.005$$

in which p is as defined before. Leaching of N and K (OUT 3) is assumed to be uniform for all soil-bound subsystems, whereas leaching of P is assumed to be zero. Nitrogen leaching is calculated as a percentage of mineral soil N and of fertilizer N. Potassium leaching is assumed to be a percentage of exchangeable K and fertilizer K. Soil N is defined as the amount of mineralized N in the upper 20 cm of the soil profile during the monitoring period. Fertilizer N and fertilizer K refer to mineral and organic fertilizer. The percentages of leaching for both nutrients are calculated as a function of the clay percentage of the soil and the mean annual precipitation using transfer functions based on literature data (Smaling et al., 1993):

$$\mathrm{OUT}\,3_{\mathrm{N}} = (\mathrm{Soil\,N} + \mathrm{Fertilizer\,N}) \times (2.1 \times 10^{-2} \times p + 3.9) \quad \mathrm{clay} < 35\%$$

$$\mathrm{OUT}\,3_{\mathrm{N}} = (\mathrm{Soil\,N} + \mathrm{Fertilizer\,N}) \times (1.4 \times 10^{-2} \times p + 0.71) \quad 35\% < \mathrm{clay} < 55\%$$

$$\mathrm{OUT}\,3_{\mathrm{N}} = (\mathrm{Soil\,N} + \mathrm{Fertilizer\,N}) \times (7.1 \times 10^{-3} \times p + 5.4) \quad \mathrm{clay} > 55$$

$$\mathrm{OUT}\,3_{\mathrm{K}} = (\mathrm{Exch.\,K} + \mathrm{Fertilizer\,K}) \times (2.9 \times 10^{-4} \times p + 0.41) \quad \mathrm{clay} < 35\%$$

$$\mathrm{OUT}\,3_{\mathrm{K}} = (\mathrm{Exch.\,K} + \mathrm{Fertilizer\,K}) \times (2.9 \times 10^{-4} \times p + 0.26) \quad 35\% < \mathrm{clay} < 55\%$$

$$\mathrm{OUT}\,3_{\mathrm{K}} = (\mathrm{Exch.\,K} + \mathrm{Fertilizer\,K}) \times (2.9 \times 10^{-4} \times p + 0.11) \quad \mathrm{clay} > 55\%$$

in which OUT 3_{K} and OUT 3_{K} are the amount of N and K (kg ha^{-1} yr^{-1}) leached, clay is the clay content of the topsoil (%), p is as before and, Soil N, Fertilizer N, Exch. K are as explained in the text. The percentage of N, lost through denitrification is assumed to be the same for each primary production compartment and is calculated as a function of the clay percentage of the soil and the mean annual precipitation using a transfer function (Smaling et al., 1993). Gaseous losses (OUT 4) are calculated by multiplying the loss percentage by fertilizer N + mineralized soil N:

$$\text{OUT } 4_N = (\text{Soil N} + \text{Fertilizer N}) \times (-9.4 + 0.13 \times \text{clay} + 0.01p)$$

in which OUT 4_N is the gaseous N losses (kg ha^{-1} yr^{-1}), p and clay is as before, Soil N, Fertilizer N is as explained in the text. Erosion (OUT 5), can occur in any of the primary production compartments. Soil loss (kg ha^{-1} yr^{-1}), is estimated using the universal soil loss equation (Wischmeier and Smith, 1978), but it is also possible to use specific soil loss figures for each primary production compartment if available. Soil loss is converted to nutrient loss (kg ha^{-1} yr^{-1}), using the total N, P and K-content (%), of the soil and an enrichment factor.

3.2.3. Method 3: other approaches

Input through external grazing (IN 2c) occurs when animals are grazed outside the farm during the day and they are corralled within the farm, during the night. This results in a net influx of nutrients partly present in body weight of the animals and partly in the manure excreted during night time. The consumption of bush and roadside grasses by the browsing animals when outside the farm, is calculated from the daily feed requirement of the group. It is assumed that grasses are infinitely available and that the animals consequently manage to consume a quantity of feeds equal to their daily requirements. The uptake and excretion of nutrients is calculated using feed conversion factors. A so-called 'return percentage' is used to calculate the amount of manure that is imported into the farm. The 'return percentage' is defined as the percentage of the total amount of manure excreted by the browsing animals that is returned to the farm and depends on the livestock management.

It is assumed that symbiotic N-fixation (IN 4a), may take place within all primary production systems. For primary production compartments with leguminous annual or perennial species, a crop-specific percentage of the total N uptake is attributed to symbiotic N-fixation. The total N uptake is defined as the sum of the amount of N in the harvested product and the crop residues (either removed and quantified as OUT 1+ OUT 2+ OUT 4c + Fl 3a or remaining on the field). This is always an under-estimation of the real N uptake because the nutrients in plant roots are ignored. This is done because usually no information is available on the quantities of plant roots.

Sedimentation (IN 5) can be the result of two different processes: irrigation and natural flooding. Sedimentation from erosion processes is not included because the available data does not usually allow for such a sophisticated analysis. If irrigation takes place a specification of the amount of irrigation water and its chemical composition used for each primary production system should be given.

Losses through burning of crop residues (OUT 4c) are calculated by user-defined loss fractions for N, P and K. The default values are 0.8, 0.0 and 0.0, respectively. All nutrients in food items consumed by the farm family are considered to be lost from the system (OUT 6) because human excreta mostly end up in deep latrines outside the system's boundary under Kenyan circumstances.

The actual feed consumption (Fl 1a, 2b, 3b and 4) is calculated by allocating the feeds present in a certain area to a livestock group proportionally to (i) the average confinement figures of each group to the area, (ii) the daily feed requirement (kg $head^{-1}$ day^{-1}) of the species, and (iii) the number of animals in the group. It is assumed that the feeds are consumed in a preferred order being: imported feeds, household waste, crop residues, local vegetation. After the external feeds the household wastes and the crop residues have been consumed entirely the animals continue consuming local vegetation until their daily demand has been met. When the feed requirements of the animals have been met, leftovers of imported feeds, household waste and crop residues contribute to the soil subcompartment of the primary production compartment in which they are located. The total amount of excreted manure (Fl 5a) is calculated from the total consumption of feeds (kg $group^{-1}$) and the total consumption of nutrients (kg $group^{-1}$), using feed conversion factors. The manure is allocated to primary production compartments and corrals proportionally to the confinement of the groups. The manure excreted on fields is directly allocated to the soil subcompartment of the primary production compartment. The manure excreted in corrals is assumed to be subject to losses which are calculated using user defined loss percentages for leaching (OUT 3b) and gaseous losses (OUT 4b). The remaining manure and nutrients are redistributed over the fields using farmers' figures on redistribution (Fl 5b).

4. ECCAL for determination of economic performance

4.1. Introduction

Fig. 3 presents in simplified form the main links between farm and household and between those two entities and the rest of the economic system. The farm household provides the labour for farm production and in return it receives income in the form of cash and subsistence items for consumption. Besides family labour the farm uses goods and services from the rest of the economy which are paid for usually in cash but sometimes in kind. Farm output is divided between production for family uses (subsistence) and output sold to the rest of the economy and payments in kind. The household also uses goods and services from the rest of the economy which are normally paid for in cash. Most households also have off-farm employment for which remuneration in cash or kind will be received.

ECCAL applies a farm concept which is similar to that used in NUTCAL in order to link the nutrient flows to the economic flows. Fig. 4 shows the major economic flows for the farm concept.

The results produced by ECCAL can basically be divided into two groups: (i) farm household characteristics and (ii) performance indicators at farm and activity level. The characteristics and indicators combined with the nutrient balances form the basis for the analysis of farming systems the setting of priorities for potential and appropriate technologies the identifica-

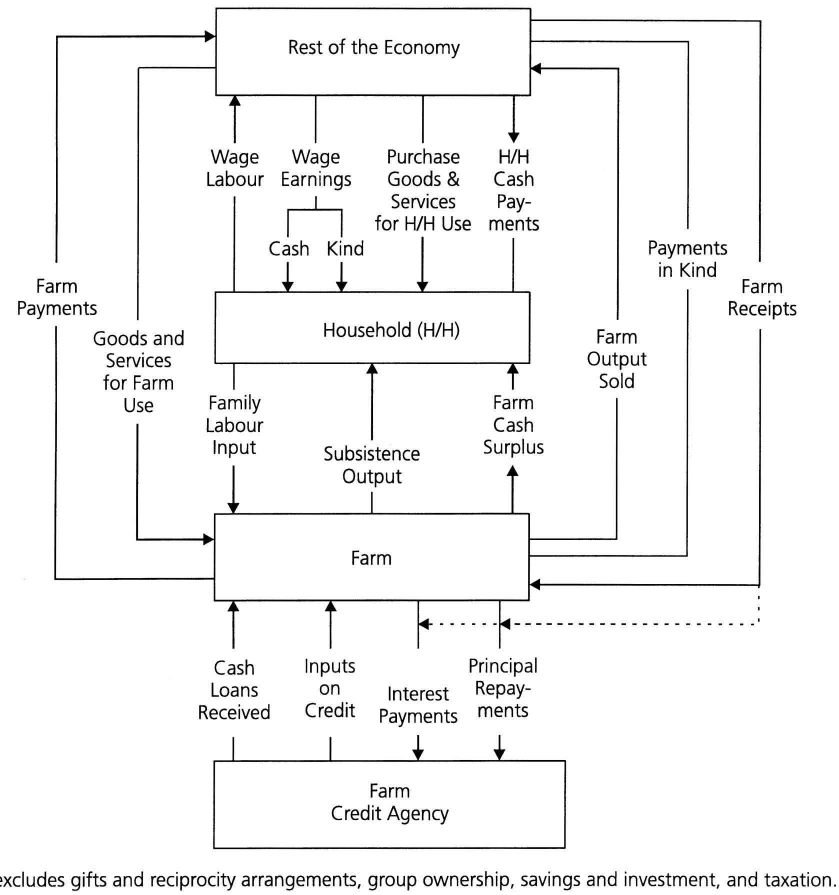


Fig. 3. Relation between the farm and its economic environment.

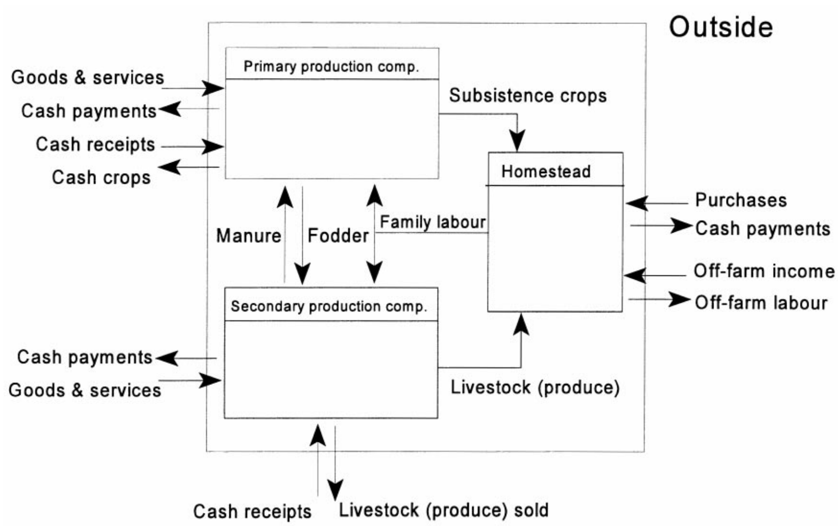


Fig. 4. Farm concept with its economic flows as used in ECCAL.

tion of relevant policy tools to facilitate adoption of these technologies.

4.2. Farm household characteristics

Besides the general information about the farms gathered during the farm selection process, a number of farm household characteristics are quantified like consumer units, labour units, R-value etc. (for a complete list see Table 3). During the farm inventory the value of the equipment, livestock and land held in ownership are recorded. Because generally hardly any cash is kept, inventories of cash balances are not included.

4.3. Economic performance indicators

Performance indicators are basically distinguished at activity level and at farm level (Dillon and Hardaker, 1993). At activity level economic performance indicators are calculated only for the primary and secondary production compartments. Cash flow measures (involving actual cash transactions) and income and profitability measures (involving cash and imputed values or opportunity costs and benefits) are calculated at both levels because both the cash flow and the economic performance are relevant to farm household decisions concerning soil nutrient management. Monetary values are attached to nutrient flows being a direct result of farm management activities and are therefore limited to IN 1, IN 2, OUT 1 and OUT 2. Nutrient inflows by, for instance, deposition and biological nitrogen fixation and outflows such as leaching and gaseous losses, are not considered in the economic performance calculations. In the analysis, however, attempts are made to estimate the economic values of nutrient losses (De Jager et al., 1998b). The calculation of economic performance indicators involves inflows and outflows other than those of nutrients, for instance labour input, pesticides, animal traction etc. This leads to a different classification of inputs and outputs which is more geared towards an economic analysis (Table 4).

At activity level, gross margins and cash flows per compartment are calculated both for primary and secondary production compartments. Table 3 presents the methods of calculation.

Economic performance at farm household level is measured as net farm income. This indicator measures the reward to the farm family for its labour and management and the return to all the capital invested in the farm whether borrowed or not. The total income available to the farm family is calculated as the total family earnings which includes the net farm income plus any other household income. Because debt position is not included in this approach no distinction is

Table 3
Performance indicators assessed by ECCAL

Indicators	Quantification
Farm household characteristics	
Number of persons	–
Consumer units	[number of persons]×[consumer units](per age/sex class)
Labour units	[number of persons]×[labour units](per age/sex class)
Farm size	total area (owned+rented in/out+fallow)
R-value	[cultivated area (owned+rented in)]/[total area]
Total TLU	[TLU]×[number of livestock] (per type)
Total capital	Value of land, livestock and equipment
Land/consumer ratio	[cultivated area]/[total consumer units]
Land/worker ratio	[cultivated area]/[total labour units]
Capital – consumer ratio	[total capital]/[total consumer units]
Capital – worker ratio	[total capital]/[total labour units]
Capital – land ration	[total capital]/[cultivated area]
Activity level	
Gross margin analysis of primary production compartments	
Gross margins	[returns]−[variable costs]
Returns	Value of total output (including crop residues)
Variable costs	Value of total inputs: seeds, fertilizers, manure, residues/waste, pesticides, equipment rent, labour hire, others
Gross margin analysis of secondary production compartments	
Gross margins	[returns]−[variable costs]
Returns	[value of total output] + [value of herd growth]
Variable costs	value of total inputs: concentrates, other feeds, grazing, veterinary services, labour rent, others
Cash flow analysis of primary production compartments	
Net cash flow	[cash income]−[cash receipts]
Cash income	Value of output sold
Cash receipts	Value of inputs purchased
Cash flow analysis of secondary production compartments	
Net cash flow	[cash income]−[cash receipts]
Cash income	[value of output sold] + [value of animals sold]
Cash receipts	Value of inputs purchased
Farm household level	
Net farm income	[gross margins crops] + [gross margins livestock]−[fixed costs]
Fixed costs	land rent, equipment depreciation, equipment maintenance etc.
Family earnings	[net farm income] + [off-farm income]
Farm net cash flow	[total receipts crop and livestock activities]−[total expenditures crop, livestock and general activities]
Household net cash flow	[farm net cash flow] + [off-farm income]
Crop production intensities	
Labour–land	[crop hired labour days+crop family labour days]/[cultivated area]
Cost–land	[variable costs crop activities]/[cultivated area]
Cost–labour	[variable costs crop act−hired labour costs]/[crop hired labour days + crop family labour days]
Crop returns	
Returns to land	[total crops gross margin]/[cultivated area]
Returns to labour	[total crops gross margin−hired labour costs]/[crop hired labour days + crop family labour days]
Livestock production intensities	
Labour – TLU	[livestock hired + family labour days]/[total TLU]
Cost – TLU	[variable costs livestock act.]/[total TLU]
Cost – Labour	[variable costs livestock act.−hired labour costs]/[livestock hired + family labour days]

Table 3 (*Continued*)

Indicators	Quantification
Livestock production returns	
Returns per TLU	[total livestock gross margin]/[total TLU]
Returns to labour	[total livestock gross margin−hired labour costs]/[livestock hired + family labour days]
Farm level returns	
Returns to land	[net farm income−value family labour −capital costs]/[area owned land]
Returns to labour	[net farm income−capital costs−value owned land]/[total family labour days]
Returns to capital	[net farm income−value family labour −value owned land]/[capital livestock and equipment]
Non-farm income	
Return to labour	[off-farm income]/[off-farm income labour days]
Family earnings	
Family earnings per person	[family earnings]/[number of persons]
Family earnings per cons. unit	[family earnings]/[total consumer units]

Table 4
Categories of inputs and outputs in the economic calculations at activity level for primary and secondary production compartments

Compartment	Inputs	Outputs
Primary production compartments	Seeds	Returns (crops and crop residues)
	Fertilizers	
	Manure	
	Residues/wastes	
	Pesticides	
	Equipment hire	
	Labour hire	
	Other	
Secondary production compartments	Concentrates	Returns (animal products and hiring out)
	Other feeds	Herd development
	Grazing	
	Veterinary services	
	Labour hire	
	Other	

made between paid and calculated interest. At farm level a number of more specific performance indicators are calculated for the sum of the primary and secondary production compartments as well as the returns to invested capital family labour and land (see Table 3). The cash flow at farm level is expressed as the farm net cash flow and the household net cash income.

4.4. *Quantifying indicators*

The quantification of the indicators is implemented according to the definitions presented in Table 3 using data collected during the monitoring phase. For cases where no actual prices can be recorded, for instance because no cash transaction is involved, imputed values are estimated based upon opportunity costs and benefits. In general net selling or farm gate prices are used.

5. Discussion

5.1. *Strengths of farm-NUTMON*

Farm-NUTMON allows study of a farm in an integrative, holistic way, capturing a real and complex farm situation, taking into account the effects of the many different activities on the farm (crop and livestock activities, manure management, garbage management and off-farm activities), on the nutrient stocks and flows and the economic performance of the farm. Farm-NUTMON integrates biophysical and economic research in order to estimate the extent to which the farm household generates its income from soil nutrient mining and to assess the economic financial and labour-related possibilities and constraints of the adoption of alternative integrated nutrient management technologies.

Farm-NUTMON uses information available from previous scientific work to estimate leaching, gaseous losses, erosion and other flows. On the spot quantification of these flows is usually not feasible because of the high costs and long duration of the experiments. Therefore, these flows are often not taken into consideration resulting in an incomplete picture of farm management. Farm-NUTMON is therefore applicable in low-data environments. The quantification of nutrient flows and economic performance indicators is transparent. This allows differentiation between hard data on one hand and estimates/assumptions on the other hand.

5.2. *Weaknesses of farm-NUTMON*

The nutrient balance as such is an incomplete indicator for sustainability with respect to soil fertility because it does not differentiate between nutrients in soil solution and in different types of organic matter (Shepherd and Soule, 1998). Interpretation of a balance is difficult because it is not directly related to soil nutrient stocks and their replenishment by weathering of minerals mineralization and desorption. Farm-NUTMON is a static tool that can only be used for diagnosing a particular prevailing farming system. Simulation of longer periods of nutrient management is not possible making it difficult to gain insight into long-term effects of farm management on soil fertility and productivity.

Although the use of transfer functions is seen as an advantage it also has its drawbacks. The transfer functions applied are not site specifically validated leading to an unknown level of uncertainty in the flows quantified in this way. Besides, the real losses by leaching are over-estimated because part of the N leached to below the 30 cm layer can still be available for plant growth. Nutrient inflow from subsoil exploitation has not yet been incorporated in the model although in agro-forestry systems this flow may represent a considerable input at farm level. Because of lack of data, no corrections are made, for nutrients available in deeper layers in reach of plant roots after erosion. The quantification of the consumption of feeds and the amounts of manure excreted, is based on simple assumptions leading to uncertainties in some of the internal flows.

Information relating to off-farm income is usually of poor reliability, as farmers are reluctant to give this information. Imputed values of non-traded goods are estimated based on secondary data; for more reliable figures, a more structured method needs to be developed.

During the fieldwork it was observed that the comprehensive integrated approach leads to a rather voluminous questionnaire and lengthy interviews. This might cause a certain fatigue with the farmers, leading to ‘easy answers’. Besides some farmers tend to change their nutrient management behaviour after several interviews. Although this is good as a learning process it is undesirable when ‘diagnosing’ the farming system.

The conceptual structure of the tool is tailored to Kenyan farming systems. This implies that application to different systems would require adaptation of the tool.

5.3. *Future development avenues*

The current approach is rather extractive and it is desirable to embed this tool into a more participatory approach (Defoer et al., 1998; Deugd et al., 1998). This could ensure a more efficient use of the ideas and knowledge of farmers and increase the motivation of farmers to participate in research and to test and adopt new technologies. The farmers’ motivation to participate in the research can also be increased by reducing the time required for the diagnostic phase and starting immediately after the PRA with a process of participatory technology development and monitoring of changes.

A link should be made between the nutrient budgets on the one hand and soil organic matter available nutrients and total nutrient stocks on the other hand in order to improve the interpretation of the nutrient balance. It is also important to put more emphasis on an indication of the degree of uncertainty in the flows. Improvement of loss estimates can be achieved by the development of more sophisticated transfer functions and model approaches for quantifying leaching, gaseous losses, erosion and flows related to feed consumption and manure excretion by livestock. Existing knowledge of subsoil exploitation should be incorporated. In order to improve the estimation of the impact of nutrient management on household income other strategies to gather data on off-farm income should be developed.

The amount of work involved can be reduced and the participation increased by developing alternative and more creative tools and self-recording systems to gather the necessary information. The questionnaire, the data entry facilities and the presentation of results should be made more user friendly, in order to raise the quality of the information obtained. For application in new areas the structure of the tool should be more flexible and should allow for accommodation of unforeseen features within a farm.

Acknowledgements

The Rockefeller Foundation is gratefully acknowledged for supporting this research.

References

Defoer, T., De Groote, H., Hilhorst, T., Kanté, S., Budelman, A., 1998. Participatory action research and quantitative analysis for nutrient management in Southern Mali: a fruitful marriage? Agric. Ecosyst. Environ. 71, 217–230.

Deugd, M., Röling, N., Smaling, E.M.A., 1998. A new pracxeology for integrated nutrient management: facilitating innovation with and by farmers. Agric. Ecosyst. Environ. 71, 271–285.

De Jager, A., Nandwa, S.M., Okoth, P.F., 1998a. Monitoring nutrient flows and economic performance in African farming systems (NUTMON) I. Concepts and methodologies. Agric. Ecosyst. Environ. 71, 39–50.

De Jager, A., Kariuki, I., Matiri, F.M., Odendo, M., Wanyama, J.M., 1998b. Monitoring nutrient flows and economic performance in African farming systems (NUTMON). IV. Linking farm economic performance and nutrient balances in three districts in Kenya. Agric. Ecosyst. Environ. 71, 83–94.

Dillon, J.L., Hardaker, J.B., 1993. Farm management research for small farmer development. Rome, FAO, Farm Systems Management, Series 6.

Shepherd, K.D., Soule, M.J., 1998. Soil fertility management in West Kenya: dynamic simulation of productivity, profitability and sustainability at different resource endowment levels. Agric. Ecosyst. Environ. 71, 133–147.

Smaling, E.M.A., Stoorvogel, J.J., Windmeijer, P.N., 1993. Calculating soil nutrient balances in Africa at different scales. II. District scale. Fert. Res. 35, 237–350.

Smaling, E.M.A., Fresco, L.O., 1993. A decision-support model for monitoring nutrient balances under agricultural land use (NUTMON). Geoderma 60, 235–256.

Stoorvogel, J.J., Smaling, E.M.A., 1990. Assessment of soil nutrient depletion in sub-Saharan Africa: 1983–2000, Wageningen, DLO-Winand Staring Centre. Report 28.

Stoorvogel, J.J., Smaling, E.M.A., Janssen, B.H., 1993. Calculating soil nutrient balances in Africa at different scales. I. Supranational scale. Fert. Res. 35, 227–235.

Van den, Bosch, Maobe, H.S., Ogaro, V.N., Gitari, J.N., Vlaming, J., 1998. Monitoring nutrient flows and economic performance in African farming systems (NUTMON). III. Monitoring nutrient flows and balances in three districts in Kenya. Agric. Ecosyst. Environ. 71, 65–82.

Wischmeier, W.H., Smith, D.D., 1978. Predicting rainfall erosion losses from cropland. A guide for selection of practices for soil and water conservation. Washington, DC, Agricultural Handbook, 282 p.

PART 3 Implementation of NUTMON approach and integration in innovation systems in smallholder agriculture

Chapter 4 Monitoring performances of farming systems in three different agro-ecological zones in Kenya

De Jager, A., Kariuki, I., Matiri, F.M., Odendo M. and Wanyama, J.M., 1998.

Monitoring nutrient flows and economic performance in African farming systems (NUTMON). IV. Monitoring of farm economic performance in three districts in Kenya.

Agriculture, Ecosystems and Environment 71: 81-92.

ELSEVIER

Agriculture, Ecosystems and Environment 71 (1998) 81–92

Agriculture Ecosystems & Environment

Monitoring nutrient flows and economic performance in African farming systems (NUTMON)
IV. Linking nutrient balances and economic performance in three districts in Kenya

A. de Jager[a,*], I. Kariuku[b], F.M. Matiri[b], M. Odendo[c], J.M. Wanyama[d]

[a]*Agricultural Economics Research Institute (LEI-DLO), The Hague, Netherlands*
[b]*KARI-Regional Research Centre, Embu, P.O. Box 27, Kenya*
[c]*KARI-Regional Research Centre, Kakamega, P.O. Box 169, Kenya*
[d]*KARI-Regional Research Centre, Kisii, P.O. Box 532, Kenya*

Abstract

At the national level, agricultural production in Kenya is characterized by a negative nutrient balance and a downward trend in food production per capita and can therefore be classified as unsustainable. However, little information is available concerning ecological and economic sustainability of the various production systems at farm level. A one year monthly monitoring activity was conducted in the season 1995/1996 in three districts with the participation of 26 farm households covering the major existing farming systems in these districts, in which data were collected on agronomic and economic aspects of the farm management. The average N-balance at farm level is -71 kg ha^{-1} yr^{-1} with large variations among farms ranging from -240 kg ha^{-1} yr^{-1} to $+135$ kg ha^{-1} yr^{-1}; the average K-balance is slightly negative, the P-balance slightly positive. Net farm income shows no relation with the nutrient balance. A high market orientation on the other hand correlates with a more negative N- and K-balance. The market-oriented farms located in the highly populated areas are characterized by intensive crop and livestock activities, import nutrients through fertilizers and/or animal feeds, but insufficient to compensate the outflow through marketed products, leaching and erosion. The average annual net farm income amounts to US$ 1490 per farm, with large variations among farms. Average returns to family labour (US$ 2.2 per day[1]) and returns to land (US$ 91 per ha[1]) are comparable or higher than unskilled wage rates and annual land rent respectively, but 50% of the farms perform below these rates. Market oriented farms have an economic performance that is similar to subsistence oriented farms. Off-farm income, however, is essential for large groups of small-scale farm households to achieve economic viability: without additional off-farm income, 54% of the farms in the sample are estimated to be below the poverty line. The replacement costs of mined nutrients amounts to 32% of the average net farm income.

At crop level the cash crops tea and coffee realise higher gross margins and considerably lower nutrient mining levels than the major food crops maize and maize-beans. It is concluded that a multi-disciplinary monitoring activity at farm level, contributes to targeting and prioritization of development options aimed at optimization of soil nutrient management. © 1998 Elsevier Science B.V. All rights reserved.

Keywords: Kenya; Nutrient balance; Economic performance; Ecological sustainability; Economic sustainability

*Corresponding author. Tel.: +31-70-330-8341; fax: +31-70-361-5624; e-mail: a.dejager@lei.dlo.nl

0167-8809/98/$ – see front matter © 1998 Elsevier Science B.V. All rights reserved.
PII: S0167-8809(98)00133-9

1. Introduction

In sub-Saharan Africa (SSA) it is increasingly difficult to satisfy short-term production needs and long-term sustainability demands at the same time. Forced by the need to produce more staple crops for a growing population and to grow cash crops to integrate in the monetary economy, farm households replaced once stable systems by more intensive systems relying heavily on external inputs, or moved into more ecological fragile areas. Implementation of Structural Adjustment Policies resulted in increased prices of external inputs, but price levels of agricultural products decreased and only a limited growth in productivity was realised. These developments have forced farm households to exploit soil nutrient resources, leading to negative nutrient balances and declining soil fertility in most countries in SSA. At national level, two indicators illustrate the unsustainability of agricultural production: nutrient outputs exceed inputs by 40 kg N, 3 kg P and 30 kg K ha^{-1} yr^{-1} (Stoorvogel and Smaling, 1990) and per capita food production has been declining over the past 7 years (Fig. 1; FAO, 1996). However, little information is available on ecological and economic sustainability of the production systems at farming system level. In order to turn the tide, a comprehensive and targeted approach for specific farming systems is required, involving appropriate technologies in the framework of Integrated Nutrient Management, farmers' knowledge and relevant policy instruments (Mokwunye et al., 1996). Such an approach requires detailed knowledge of the farm management at farm household level in the various agro-ecological zones and its impact on the nutrient balance and economic performance. An earlier developed model for nutrient monitoring (NUTMON) and a proposed framework for development (Smaling et al., 1996) have been applied to identify the level of ecological and economic sustainability in Kenyan farming systems.

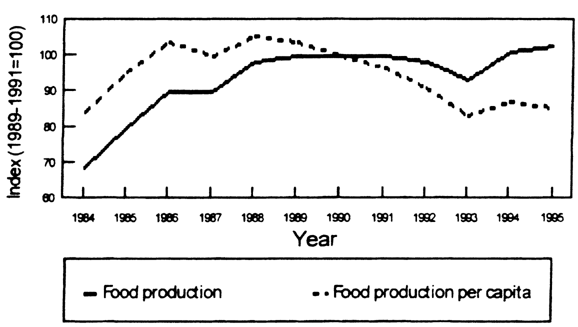


Fig. 1. Food production indices Kenya.

2. Methods

Three districts were selected for monitoring, covering the wide agro-ecological and socioeconomic variability of existing farming systems in the high- and medium potential areas of Kenya. Because methodology development is a major objective, the farm selection procedure was aimed at covering the wide variety of existing farming systems of major importance in the district, rather than obtaining a district representative sample. Based upon secondary data, satellite images and expert knowledge, different land use zones (LUZs) were defined and described. Thereafter a participatory rural appraisal (PRA) was organised to describe qualitatively the various LUZs, identify major problems and constraints and lay the foundation for the actual farm selection (De Jager et al., 1998). Per LUZ two or three farm households were selected based upon willingness to participate in the monitoring programme and a number of selection criteria for representativeness within the LUZ, such as cropping pattern, livestock activities, farm size, farm management practices, product marketing and off-farm income activities.

For analysis of the nutrient flows the NUTMON-model is applied which distinguishes between three types of units: crop activities (primary production units), livestock activities (secondary production units) and the homestead and a set of six inflows (mineral fertilizer, organic manure, wet and dry deposition, biological nitrogen fixation, sedimentation and subsoil exploitation), six outflows (crop products, crop residues, leaching, denitrification, water erosion and human faeces), and six internal flows (consumption of external feeds, reuse of household waste, reuse of crop residues, grazing, reuse of manure, and home consumption (Table 1; Van den Bosch et al., 1998a). In the ECMON-model basic economic performance indicators at the activity and farm household level as well as a number of general farm household charac-

Table 1
Distinguished types of nutrient flows at farm level in NUTMON

IN flows	Out flows	Internal flows
IN1 Mineral fertilizers	OUT1 Farm products sold	FL1 Feeds
IN2 Organic inputs	OUT2 Other organic products	FL2 Household waste
IN3 Atmospheric deposition	OUT3 Leaching	FL3 Crop residues
IN4 Biological nitrogen fixation	OUT4 Gaseous losses	FL4 Grazing of vegetation
IN5 Sedimentation	OUT5 Runoff and erosion	FL5 Animal anure
IN6 Subsoil exploitation	OUT6 Human faeces	FL6 Farm products to household

teristics are quantified. For both scale levels, cash flow measures and income and profitability measures are calculated. At activity level, the main indicators were gross margins (returns minus variable costs) and cash flows (cash income minus cash receipts) per unit area and at farm household level net farm income (total gross margins minus fixed costs), family earnings (net farm income plus off-farm income).

A structured questionnaire was used to collect data with a monthly recall period on quantity and prices of inputs and outputs of crop and livestock activities, growth of the herd, confinement of livestock, redistribution of manure, stock of household staple crops, labour input and off-farm income. Beside this monthly monitoring, a farm inventory was conducted, primary data collected (soil samples, nutrient contents of products, market prices, etc.) and secondary data gathered (soil maps, agro-climate data, relevant research results). For non-traded goods and family labour opportunity costs were estimated based on the average market rates.

The economic performance indicators were analysed using basic descriptive statistical techniques. Non-parametric correlation was used to investigate relations between the various economic and agronomic characteristics. In order to evaluate the economic sustainability of the farming system, the following indicator has been applied:

$$\mathrm{IMEQ} = \mathrm{FE}/\mathrm{MFE}$$

in which IMEQ is the income minimum-expenditure quotient; FE is family earnings and MFE is the minimum family expenditures.

A variety of methods have been developed to internalise environmental issues in the traditional economic analyses (Harrington, 1992; Ehui and Spencer, 1993; van Pelt, 1993; Bojö, 1996). For nutrient mining, the replacement costs method and productivity method are most generally used. For application of the productivity method, estimations need to be made of the future loss of productivity from nutrient mining (Bishop and Allen, 1989). Application of this method, requires additional data such as simulation estimates of crop responses to different crop nutrient levels in the soil and effects on crop-livestock interactions (Shepherd and Soule, 1998). The replacement cost method on the other hand is relatively simple and can be applied with the current available data set. In this method, the costs to replace damaged productive assets, such as nutrients in this case, are estimated. The depleted nutrients are considered to have an economic value equal to the market value (at farm gate prices) of an equivalent amount of fertilizers. Different efficiency factors of fertilizers are not considered in this calculations. The sustainability of a farming system can then be estimated through relating the costs of replacement to the net farm income. The farmers income sustainability quotient (van der Pol, 1993) can then be defined as follows:

$$\mathrm{FISQ} = 1 - (\mathrm{NDV}_{\mathrm{farm}}/\mathrm{NFI}) \qquad (-\infty < \mathrm{FISQ} \leq 1)$$

in which FISQ is the farmers income sustainability quotient; $\mathrm{NDV}_{\mathrm{farm}}$ is the nutrient deficient value at replacement costs at farm level and NFI is the net farm income. Also at activity level a similar indicator can be defined:

$$\mathrm{GMSQ} = 1 - (\mathrm{NDV}_{\mathrm{act.}}/\mathrm{GM}) \qquad (-\infty < \mathrm{GMSQ} \leq 1)$$

in which GMSQ is the gross margin sustainability quotient; $\mathrm{NDV}_{\mathrm{act.}}$ is the nutrient deficient value at replacement costs at activity level and GM is the gross margin.

Table 2
Basic farm characteristics

	Districts						Total	
	Kissi		Kakamega		Embu			
	Mean	Standard deviation	Mean	Standard deviation	Mean	Standard deviation	Mean	Standard deviation
Cultivated area (ha)	3.8	2.4	5.1	3.9	4.5	7.1	4.5	5.3
Crop diversity (No.)	9	2	9	2	8	2	9	2
Value implements (US$)	235	220	270	235	200	180	220	200
Parcels (No.)	3	1	2	1	2	1	2	1
Plots (No.)	18	6	15	7	10	3	14	6
TLU (units)	4	3	5	3	3	2	4	3
Livestock diversity (No.)	3	1	3	1	3	1	3	1
Household members (No.)	9	1	11	4	8	3	9	3

3. Results

3.1. Farm household level

Each district is characterized by a large variation in agro-ecological zones and corresponding farming systems and characteristics. The average cultivated area of the sample farms amounts to 4.5 ha (Table 2). The farms have a relatively high farm size compared with the estimated average holding size at provincial level which is: 1.4 ha, 1.7 ha and 2.2 ha in Nyanza, Western and Eastern province respectively (World Bank, 1995). The level of mechanisation is low with an average value of implements of US$ 220 per farm, of which wheel barrows, knapsack sprayers and chaff cutters are the major capital intensive implements.

The high pressure on land in Kisii, is illustrated by the high land fragmentation compared with the other districts. All the farms have a high degree of diversification, with an average of nine different crops or crop mixtures and three different types of livestock. The number of livestock expressed in Tropical livestock units (TLU) is slightly higher in Kisii and Kakamega district compared with Embu. The average farm household comprises nine persons, varying from 3–19.

Table 3 (derived from Van den Bosch et al., 1998b) shows that the farms in the sample are mining nitrogen (N) at an average level of 71 kg ha^{-1} yr^{-1} (Table 2), the potassium (K) balance is slightly negative (−9 kg ha^{-1} yr^{-1}), the phosphorus (P) balance slightly positive (+3 kg ha^{-1} yr^{-1}). The average partial N-balance, consisting of the nutrient flows in

Table 3
Nutrient flows at farm level

	Districts						Group total	
	Kissi		Kakamega		Embu			
	Mean	Standard deviation	Mean	Standard deviation	Mean	Standard deviation	Mean	Standard deviation
N-balance (kg ha^{-1} yr^{-1})	−102	29	−72	78	−55	79	−71	71
P-balance (kg ha^{-1} yr^{-1})	−2	9	−4	10	9	17	3	15
K-balance (kg ha^{-1} yr^{-1})	−34	21	18	53	−15	71	−9	53
Partial N-balance (kg ha^{-1} yr^{-1})	10	11	35	41	45	52	37	50
N-inflow fertilizers (kg ha^{-1} yr^{-1})	16	12	12	25	29	35	21	28
N-inflow organics (kg ha^{-1} yr^{-1})	14	7	42	52	32	37	31	43
N-outflow products (kg ha^{-1} yr^{-1})	18	8	20	25	16	17	17	18

direct farm inputs and product outputs and excluding, however is positive. Farmers apparently import more nutrients through inputs than are exported through sale of products, but factors as leaching, erosion and home consumption cause the total balance of N to be negative. No significant differences among districts are observed, although in Kisii district the mining levels of N and K appear slightly higher. On average 21 kg ha^{-1} yr^{-1} of N is imported through fertilizers, but 46% of the farms apply less than 5 kg ha^{-1} yr^{-1} of N in fertilizers. N-inflow through organics (organic feeds and outside grazing) contributes more to the N-balance than fertilizers (31 kg ha^{-1} yr^{-1} on average). Especially in Kakamega high levels are observed, mainly because of grazing outside the farm.

The average net farm income amounts to US$ 1490 per farm per year (Table 4), again with large variations among farms. Between the districts no statistically significant differences are observed. Crop and livestock activities contribute equally to the net farm income, although in Kakamega the share of livestock activities is significantly higher compared with the other districts. The average economic performance of the farm activities is satisfactory, when looking at the realised returns to land and to family labour, which are above the districts average land rent (US$ 55 ha^{-1} yr^{-1}) and wages for unskilled labour (US$ 1.5 day^{-1}) respectively. However, there is a large variation among the farms and 46% of the farms in the sample realise lower returns than these district averages.

The average annual farm net cash flow amounts US$ 675, with no statistically significant differences among districts. Crop and livestock activities contribute equally to the total farm cash income, but only in Kakamega is a significantly higher contribution of livestock observed. The average market orientation of the farms, expressed in the percentage of the total revenues of crop and livestock outputs sold, is 45% varying from complete subsistence (0%) to almost fully market oriented (95%). The selected farms in Kakamega district appear more subsistence oriented, although the difference is not statistically significant. On average 773 labour days are used for farm activities, equivalent to two full-time persons. Around 16% of this labour is hired, again with a large variation between farms. The labour intensity of crop activities in Kisii and Embu is considerably higher than in the more extensive farming systems in Kakamega. Labour intensity in livestock between the districts is comparable.

The net farm income shows no relation to the nutrient balance, only a logical positive correlation with the number of livestock and cultivated area (Table 5). Market orientation correlates positively with net cash flow, N-inflow through fertilizers (IN1), N-outflow through products (OUT1), internal manure applied, labour intensity for crop activities,

Table 4
Economic performance indicators

	District						Total	
	Kisii		Kakamega		Embu			
	Mean	Standard deviation	Mean	Standard deviation	Mean	Standard deviation	Mean	Standard deviation
Net farm income (US$ $farm^{-1}$)	1435	1235	1655	1180	1420	1200	1490	1165
Farm net cash flow (US$ $farm^{-1}$)	490	475	525	635	855	1200	675	910
Returns to land (US$ ha^{-1})	−200	580	110	475	235	980	90	765
Returns to family labour (US$ day^{-1})	1.4	1.4	2.4	2.1	2.5	2.7	2.2	2.3
Share crops in gross margin (%)	49	27	19	20	68	23	49	31
Share crops in cash income (%)	51	34	18	19	73	39	50	39
Market orientation (%)	48	15	30	15	55	33	45	27
Total labour input (days $farm^{-1}$)	1059	308	767	434	634	173	773	337
Share hired labour (%)	20	13	15	16	15	21	16	17
Labour intensity crops (days ha^{-1})	258	181	176	194	281	212	244	198
Labour intensity livestock (days TLU^{-1})	65	33	63	49	68	75	66	58

Table 5
Main significant correlations of net farm income, market orientation, Farm size and N-balance with major farm and farm management characteristics

Characteristic	Positive correlation*	Negative correlation*
Net farm income (US$ farm^{-1})	Cultivated area (ha)	
	TLU	
Market orientation (% sold of gross returns)	Share crops in cash income and total gross margin (%)	Cultivated area (ha)
	Farm net cash flow (US$ farm^{-1})	N- and K-balance (kg ha^{-1} yr^{-1})
	N-inflow through fertilizers (kg ha^{-1} yr^{-1})	TLU
	Internal manure applied (kg ha^{-1} yr^{-1})	
	Labour days per ha crops (days ha^{-1})	
	N-outflow through products (kg ha^{-1} yr^{-1})	
	Zero-grazing unit (yes/no)	
Cultivated area (ha)	Implement value (US$ farm^{-1})	Internal manure applied (kg ha^{-1} yr^{-1})
	Net farm income (US$ farm^{-1})	Labour days crops (days ha^{-1})
	TLU	Market orientation (%)
		N-outflow through products (kg ha^{-1} yr^{-1})

*(P=0.05)

share of crops in net farm and cash income and occurrence of zero-grazing units. On the other hand, a higher market orientation corresponds with a lower cultivated area, a more negative N and K balance and a lower number of livestock. The cultivated area is positively related to the value for implements and the number of livestock and negatively to the application levels of on-farm produced manure, labour intensity, market orientation and the level of nutrients leaving the farm through agricultural products sold.

In order to target technical and policy interventions to specific farming systems it is necessary to investigate whether groupings can be made, which distinguish themselves in farm management practices, level of nutrient mining, economic performance and farm household characteristics. From the above analysis it appears that market orientation can be used as discriminating factor for nutrient balances and management aspects. Three groups of market orientation are distinguished: <33%, 33–66% and >66% of the gross revenues sold. The number of farms in the 3 groups are 9, 11 and 6 respectively; in Embu district the share of market oriented farms (>66%) is highest and in Kakamega district the lowest.

Table 6 presents the averages of the most relevant farm characteristics. Subsistence oriented farms (<33%) have a significantly less negative nutrient balance for N and K than market oriented farms (>66%). The partial balance for N is positive in all three groups, but the inflow through fertilizers increases with the market orientation. Inflow through organic sources on the other hand decreases with the market orientation because of higher occurrence of zero grazing management (less outside grazing and feeding from on-farm produced napier grass) and lower total number of livestock. It should be realised that on the subsistence-oriented farms, the nutrient balance is relatively positive through concentration of nutrients from grazing land to the cultivated area for arable crops. The sustainability of the system is therefore related to the grazing to arable land ratio and increasing land pressure may lead to a decline of this ratio. The market orientation is related to intensification of the farming system: capital and labour intensive production on relatively small cultivated areas. No significant differences are observed between the groups in economic performance, although the farm net cash flow is considerably higher on the market oriented farms.

3.2. *Activity level*

Analysis of the most frequently occurring crops or crop mixtures is done for plots with a minimum area of 0.1 ha and where a harvest has been recorded. To facilitate comparison of gross margins between crops

Table 6
Farm management, nutrient balances and economic performance according to market orientation of farms expressed in % of gross returns sold

	Market orientation		
	<33%	33–66%	>66%
N-balance (kg ha^{-1} yr^{-1})	−26[a]	−89	−106[b]
P-balance (kg ha^{-1} yr^{-1})	−2	5	6
K-balance (kg ha^{-1} yr^{-1})	32[b]	−12[b]	−68[a]
Partial N-balance (kg ha^{-1} yr^{-1})	46	25	33
Net farm income (US$ farm^{-1})	1380	1620	1455
Returns to family labour (US$ day^{-1})	2.0	1.9	3.0
Farm net cash flow (US$ farm^{-1})	180[a]	765	1235[b]
Cultivated area (ha)	6.7	4.3	1.7
TLU	4.4[b]	4.2[b]	1.5[a]
Zero grazing unit (1=yes/2=no)	2.0[a]	1.5[b]	1.4[b]
Share livestock in total gross margin (%)	61[a]	63[a]	16[b]
N-inflow fertilizers (IN1 in kg ha^{-1} yr^{-1})	9[a]	18[a]	45[b]
N-inflow organics (IN2 in kg ha^{-1} yr^{-1})	54	21	14
N-outflow products (OUT1 in (kg ha^{-1} yr^{-1})	17	13	25
Application on-farm produced manure (kg ha^{-1} yr^{-1})	6000	4500	9000
Labour intensity crops (days ha^{-1})	179	226	373
Labour intensity livestock (days ha^{-1})	71	48	91

[a,b] the mean difference is significant at P=0.05 level.

on different farms irrespective of source of labour inputs, the costs of hired labour is excluded in the calculations of the variable costs. The returns, gross margins and variable costs of the major cash crops coffee and tea are considerably higher than of the major food crops maize and mixed crop of maize and beans (Table 7). In cash crops, fertilization (manure in coffee and fertilizers in tea) is the major cost component, and for food crops, fertilization, and seeds are equally important cost components. Harvesting of tea, led to relatively high costs of hired labour compared with the other activities. Although not statistically significant, food crops tend to have more negative nutrient balances than cash crops. The fodder crop

Table 7
Economic characteristics and nutrient balances of major crops

	Crops				
	Coffee (n=9)	Tea (n=11)	Napier grass (n=11)	Maize (n=11)	Maize-Beans (n=30)
Yield (kg ha^{-1})	2900	3300	35 000	1800	11 00[d]
Returns (US$ ha^{-1})	1355[a]	620[b]	645[b]	85[b]	205[b]
Gross margin (US$ ha^{-1})	1115[a]	470	435	50[b]	170[b]
Variable costs (US$ ha^{-1})[c]	240[a]	150	210[a]	35[bc]	35[bc]
Fertilizers (US$ ha^{-1})	50	135[a]	60	20[b]	15[b]
Manure (US$ ha^{-1})	180[a]	10[b]	140[a]	1[b]	4[b]
Hired labour (US$ ha^{-1})	60	130[a]	55	25	30[b]
N-balance (kg ha^{-1})	−36[a]	−46	−154[b]	−68	−74
P-balance (kg ha^{-1})	6	17[a]	−10[b]	−1	−2[b]
K-balance (kg ha^{-1})	−4[a]	−26[a]	−153[b]	-44	−37[a]

[a,b] the mean difference is significant at P=0.05 level.
[c] excluding costs of hired labour.
[d] maize and beans yield added.

Table 8
Added value, actual and needed expenditures costs and gross margin sustainability quotient for major crops and crop mixtures

	Crops				
	Coffee	Tea	Napier grass	Maize	Maize-Beans
Gross returns (US$ ha^{-1})	1355	620	645	85	205
Fertilization costs (US$ ha^{-1})	235	145	200	20	15
Added value (US$ ha^{-1})	1120	475	445	65	190
Replacement costs (US$ ha^{-1})	40	50	340	125	130
In % of returns					
Actual fertilization expenditures	17	23	31	23	8
Needed expenditure	20	31	84	173	70

napier grass realises high gross margins, but is in most cases an intermediate product for the livestock activities. Average nutrient balances are highly negative, but with high variations between plots and farms. The monitoring of incomplete production cycles of napier may lead to this negative balances. Manure, for example, is sometimes applied before the monitoring period whereas intensive harvesting takes place during the monitoring period.

When relating gross returns to costs of fertilizers or manure, it appears that a significant and positive relation is found only for tea. This implies that higher application levels of fertilizers lead to higher gross returns per hectare. The observed value-cost ratio of application of fertilizers on tea amounts to 2.5. For the other crops no significant relations were found.

On coffee, tea and napier grass considerably higher levels of fertilizers are applied than on food crops and also the added values realised differs considerably (Table 8). Economic studies of the Fertilizer use recommendation project (FURP) show that application of fertilizers to food crops is not economical in the short term, and the data show this is consistent with actual farm practices. However, low fertilizer use in food crops results in high replacement cost levels. The cash crops coffee and tea needed expenditures to replace the mined nutrients amounting to 20–30% of the gross returns, and for napier grass and food crops this at least amounts to 70–80% of the returns.

Contrary to crop activities, livestock, just like the remaining identified nutrient storage places in the farm (manure stock, food stock, farm family and garbage heaps) show on average positive nutrient balances (Van den Bosch et al., 1998b). No significant differences between the gross margins and nutrient balances of the three distinguished cattle management systems are found, but the more intensive zero-grazing system tends to realise higher gross margins and more positive nutrient balances than the more extensive systems (Table 9). A more detailed analysis of nutrient flows in livestock systems and between livestock, dunghill and napier grass is presented in Van den Bosch et al. (1998b).

3.3. *Sustainability indicators*

For 1992 the poverty line in rural areas was estimated at Ksh 5820 per adult equivalent unit (aeu) per

Table 9
Average nutrient balances and gross margin per head of different livestock activities

	Livestock			
	Cattle zero-grazing	Cattle semi-grazing	Cattle external- grazing	Poultry
Gross margin (US$ head^{-1})	300	175	200	3.5
N-balance (kg head^{-1})	11	7	3	0.2
P-balance (kg head^{-1})	1	1	0	0
K-balance (kg head^{-1})	12	10	5	0.2

year (World Bank, 1995). Assuming an annual inflation rate of 20%, for 1995 this poverty line is estimated to be Ksh 10057 or US$ 182 per aeu. Applying this poverty line to the farm sample, it appears that on 54% of the farms, farming activities alone are not sufficient to meet basic needs of food and non-food items. The collected data for off-farm activities appeared to be highly unreliable concerning the total amount of income generated and labour days involved. Farm households were very reluctant to provide exact data on these sources of income. The monitoring data show that on 58% of the farms, any form of off-farm income is generated with an average time involvement of 106 days per farm. Assuming an income generated of Ksh 100/day (US$ 1.8) this amounts to only 7% of the average net farm income. Other sources (World Bank, 1995), which also observe high unreliability of the data, however estimate considerable higher shares: 50% of the total rural income comes from non-farm and off-farm income.

The IMEQ relates the realised total family income to the estimated minimum needed family expenditures. When the IMEQ <1, the total family income is insufficient to meet minimum family expenditures. The average IMEQ for the farm households in the sample is 1.3, with 50% of the farms realising an IMEQ <1. When applying the results of the World-bank study that farm income is on average 50% of the total rural income, the IMEQ amounts to 2.4 with 19% of the farms realising an IMEQ <1.

Over all the farms, an average Farm income sustainability quotient (FISQ) of 0.68 is found, indicating that 32% of the net farm income is based upon nutrient mining. When differentiating according to district for Kisii, Kakamega and Embu respective FISQ values of 0.53, 0.60 and 0.80 are found, with the differences not statistically different. Table 10 presents the two sustainability indicators according to market orientation. No statistically significant differences were found, although the FISQ appears to go down with increased market orientation.

Table 10
Sustainability indicators at farm level according to market orientation

	Market orientation		
	<33%	33–66%	>66%
Farm income sustainability quotient	0.92	0.58	0.54
Income minimum expenditure quotient	1.2	1.3	1.4

At activity level the Gross margin sustainability quotients for the cash crops coffee (0.97) and tea (0.90) were significantly higher than for napier grass (0.22) and the food crops maize (−1.46) and maize-beans intercrop (0.24). This was caused by the observed differences in responses to fertilizers and the differences in input/output price ratios between cash crops and food crops.

4. Discussion

The above results prove that a detailed multi-disciplinary monitoring, provides essential information on the actually practised farm management in different farming systems and their performance in terms of nutrient mining, economic viability and cash generation. Gathering this information on current farming practices and indigenous knowledge on soil nutrient management is a vital step in initiating the participative development of technologies and policy instruments addressing the problem of soil nutrient depletion.

However, it is observed that the approach needs refining to generate more accurate data on the one hand and simplification in order to facilitate easy implementation on the other. Refinements are required in the estimation of 'difficult-to-measure' nutrient flows, and in the determination of opportunity costs, prices, labour and off-farm income. Simplification can be achieved through reduction of collection of field data through increased use of secondary data, priority setting of primary data collection according to sensitivity of these data to the nutrient balance and economic performance, training of farm households in basic record keeping and reduction of frequency of visits.

A large variation between farms has been observed in nutrient balances and economic performance. Therefore there is a need to increase the sample size of farms to facilitate a more profound analysis at the LUZ and district level. In addition seasonal and annual variation has so far not been captured. Because both yields and prices of inputs and outputs may vary considerably over time, a more reliable analysis can be made when data covering a number of seasons are available. In the long run determination of trends over time is essential to analyse the sustainability of a system.

The monitoring approach emphasises collection of quantitative data on sustainability of farming systems. Participation of farm households has been limited to assisting in the data collection and discussions on primary results. Increased participation of farm households in the analysis of the current farming systems is required to obtain a more comprehensive picture of the functioning of the farming systems, including qualitative assessments, social acceptability, farm household and community strategies (Defoer et al., 1998; Deugd et al., 1998). This will facilitate the analysis of social sustainability and covering aspects as equity, gender, community planning, farmers' organizations etc.

There is a need to capture ecological, economic and social sustainability in 'easy-to-measure' indicators at different scale levels. Such indicators should have an established relation to well defined sustainability factors. Analysis of these indicators must take place in connection with other indicators and have to include a time or dynamic factor to facilitate indication of trends over time. Research and development has so far resulted in an array of proposed sustainability indicators (Izac and Swift, 1994; Dalsgaard et al., 1995; ILEIA, 1996; Pearce et al., 1996). NGOs focus on identification of sustainability indicators used by farm households. Also in this paper some ecological and economic indicators are applied at farm and plot level like IMEQ, FISQ and GMSQ. The production sustainability indicators applied are based upon replacement costs and, for instance, Bojö (1996) argues that because of various limitations replacement cost can only be a proxy for deriving the real costs to society. It is also argued that this approach does not account for the fact that simply supplying this amount of fertilizers does not restore the nutrient content of the soil to the original state, as losses, for example because of leaching, always occur (Jansen et al., 1995). Development of simple methods to estimate future productivity losses and economic impacts because of long-term soil degradation processes are therefore required. So far, rather complicated and data demanding agronomic-economic models are available for such estimations (Schipper et al., 1995), some of them including dynamic aspects (Shepherd and Soule, 1998). It is also observed, that the currently applied nutrient mining indicators need to be related to available nutrient stocks (Van den Bosch et al., 1998a). An overall assessment of available indicators on different sustainability issues and scale levels on relevance to the target group, operational value, links to sustainability issues is required and will facilitate targeting of future monitoring activities.

Including higher scale-levels in the monitoring activities is necessary to assess instruments affecting farming systems sustainability like community decision structures and policy makers at district levels and higher. Establishing links between nutrient mining and economic viability at a higher scale level may for instance induce a change in priorities at policy level.

5. Conclusions

The indications of unsustainability of agricultural production at national level correspond with the observations at farm household level. On average 71 kg N $ha^{-1}yr^{-1}$ and 9 kg K $ha^{-1}yr^{-1}$ are mined which implies that 32% of the net farm income is based upon nutrient mining. In addition, currently, already 54% farms in the sample realise income levels from farm activities which are below the estimated poverty line. This leads to the conclusion that in the current socio-economic environment, a large portion of the farm households are producing in an economically unsustainable situation and that off-farm income is essential for large groups of small-scale farm households to achieve economic viability.

The average partial nutrient balances, consisting of nutrient flows in direct inputs and outputs are positive. This indicates that farmers apply more nutrients through inputs than are exported through sale of products, but processes such as leaching, erosion and the consumption of food grown on the farm cause the N and K balance to be negative. Much heterogeneity between farms and farming systems is observed. For instance, the market orientation of a farm appears to be a major discriminating factor for nutrient balances and farm management aspects. A high market orientation of a farming system is related to a capital and labour intensive production on a relatively small cultivated area and results in a more negative nutrient balance for N and K compared to a subsistence oriented farming system. Surprisingly the market oriented farms realise a comparable economic performance as the subsistence oriented farms. Therefore the farm income sustainability quotient tends to go down with increasing market orientation, but not statistically significant.

Cash crops including coffee and tea realise higher gross margins and considerably lower nutrient mining levels than the food crops maize and maize-beans intercrop. Apparently for farm households application of nutrients to cash crops is economically more attractive than to food crops. Unfavourable input/output price ratios apparently lead to low level nutrient application in food crops. Given the declining food production per capita and the threat of declining productivity from the observed nutrient mining, drastic changes in the economic environment are required to change this trend.

The results at crop level appear to contradict with the farm level results, where subsistence oriented farms realise less negative nutrient balances. However, the differences in livestock management on these farming systems play a crucial role: at subsistence oriented farms outside grazing results in high level of nutrient imports and at market oriented farms high losses in the cattle-dunghill-napier grass cycle occur (Van den Bosch et al., 1998b). But also other factors like higher levels of erosion and leaching occurring in the locations of market-oriented farms contribute to these differences.

The multi-disciplinary monitoring approach, although still in development, has proved to contribute to understanding the current farm management systems and to target and prioritize different development options. The observed heterogeneity, caused by differences in physical and socioeconomic environment, farm management strategies and objectives, technical knowledge etc., can be used as a starting point for inducing changes towards an increased sustainability. It is obvious from the results that market-oriented farming systems will have to follow a different strategy towards more sustainable practices than the subsistence oriented systems.

Incorporating environmental issues in the economic analysis is an appropriate way to link agronomic and economic analysis. It contributes to quantification of the financial impact of environmental degradation, provides the economic boundaries for development options and plays an essential role in policy advise. For instance, the results showing that on average 32% of the realised net farm income is based upon nutrient mining and assuming this level of mining will continue, is a clear indication for policy makers that in the long run soil fertility is declining and agricultural production is developing in an unsustainable way and that this issue needs to be addressed with the highest priority.

Acknowledgements

The Rockefeller Foundation is gratefully acknowledged for supporting this research.

References

Bishop, J., Allen, J., 1989. The on-site cost of soil erosion in Mali. World Bank Environmental Paper No. 21.

Bojö, J., 1996. The cost of land degradation in sub Saharan Africa. Ecol. Econom. 16, 161–173.

Dalsgaard, J.P.T., Lightfoot, C., Christensen, V., 1995. Towards quantification of ecological sustainability in farming systems analysis. Ecolo. Eng. 4, 181–189.

Defoer, T., De Groote, H., Hilhorst, T., Kant, J.S., Budelman, A., 1998. Participatory action-research and quantitative analysis for nutrient management in southern Mali: a fruitful marriage? Agric. Ecosyst. Environ. 71, 217–230.

De Jager, A., Nandwa, S.M., Okoth, P.F., 1998. Monitoring nutrient flows and economic performance in African farming systems (NUTMON) I. Concepts and methodologies. Agric. Ecosyst. Environ. 71, 39–50.

Deugd, M., Röling, N., Smaling, E.M.A., 1998. A new praxeology for integrated nutrient management: facilitating innovation with and by farmers. Agric. Ecosyst. Environ. 71, 271–285.

FAO, 1996. FAO Statistics Series No. 130, production volume 49, Rome.

Ehui, S.K., Spencer, D.S.C., 1993. Measuring the sustainability and economic viability of tropical farming systems: a model from sub-Saharan Africa. Agric. Econom. 9, 279–296.

Harrington, L.W., 1992. Measuring sustainability: issues and alternatives. J. Farming Syst. Res., Extension 3.

ILEIA, 1996. Tracking change; indicators to assess a moving target, ILEIA Newsletter vol. 12, pp. 3.

Izac, A.M.N., Swift, M.J., 1994. On agricultural sustainability and its measurement in small-scale farming in SSA. Ecolo. Econom. 11, 105–125.

Jansen, D.M., Stoorvogel, J.J., Schipper, R.A., 1995. Using sustainability indicators in agricultural land use analysis: an example from Costa Rica. Netherlands J. Agric. Sci. 43, 61–82.

Mokwunye, A.U., de Jager, A., Smaling, E.M.A., 1996. Restoring and maintaining the productivity of West African soils: key to sustainable development. Miscellaneous fertilizer studies No.14. IFDC, Lome, Togo.
Pearce, D., Hammilton, K., Atkinson, G., 1996. Measuring sustainable development: progress on indicators. Environ. Develop. Econom. 1, 85–101.
van Pelt, M.J.F., 1993. Ecologically sustainable development and project appraisal in developing countries. Ecol. Econom. 7, 19–42.
van der Pol, F., 1993. Analysis and evaluation of options for sustainable agriculture, with special reference to southern Mali, In: H. van Reuler., Prins, W.H. (Eds.), The role of plant nutrients for sustainable food crop production in sub Saharan Africa. VKP, Leidschendam.
Schipper, R.A., Jansen, D.M.A., Stoorvogel, J.J., 1995. Sub-regional linear programming models in land use analysis: a case study of the Neguev settlement, Costa Rica. Neth. J. Agric. Sci. 43, 83–109.
Shepherd, K.D., Soule, M.J., 1998. Soil fertility management in West Kenya: dynamic simulation of productivity, profitability and sustainability at different resource endowment levels. Agric. Ecosyst. Environ. 71, 133–147.
Smaling, E.M.A., Fresco, L.O., de Jager, A., 1996. Classifying, monitoring and improving soil nutrient stocks and flows in African agriculture. Ambio 25, 492–496.
Stoorvogel, J.J., Smaling, E.M.A., 1990. Assessment of soil nutrient depletion in sub-Saharan Africa, 1983-2000, Report 28. DLO Winand Staring Centre for Integrated Land, Soil and Water Research (SC-DLO), Wageningen, Netherlands.
Van den Bosch, H., De Jager, A., Vlaming, J., 1998a, Monitoring nutrient flows and economic performance in African farming systems (NUTMON). II. Tool development. Agric. Ecosyst. Environ. 71, 51–64.
Van den Bosch, H., Gitari, J.N., Ogaro, V.N., Gitari, J.N., Maobe, S., Vlaming, J., 1998b, Monitoring nutrient flows and economic performance in African farming systems (NUTMON). III. Monitoring nutrient flows and balances in three districts in Kenya. Agric. Ecosyst. Environ. 71, 65–82.
World Bank, 1995. Kenya poverty assessment, population and human resources division Africa region, Washington, DC.

Chapter 5 Assessing sustainability of low-external-input farm management systems; a case study in Machakos District, Kenya

De Jager, A., Onduru, D., Van Wijk, M.S., Vlaming, J. and Gachini, G.N., 2001.

Assessing sustainability of low-external-input farm management systems with the nutrient monitoring approach: a case study in Kenya.

Agricultural Systems 69: 99-118.

ELSEVIER

Agricultural Systems 69 (2001) 99–118

AGRICULTURAL SYSTEMS

www.elsevier.com/locate/agsy

Assessing sustainability of low-external-input farm management systems with the nutrient monitoring approach: a case study in Kenya

A. De Jager [a,*], D. Onduru [b], M.S. van Wijk [a], J. Vlaming [c], G.N. Gachini [d]

[a] *Agricultural Economics Research Institute (LEI-DLO), PO Box 29703, 2502 LS Den Haag, The Netherlands*
[b] *Kenya Institute of Organic Farming (KIOF), PO Box 34972, Nairobi, Kenya*
[c] *Alterra – Research Institute for the Green World, PO Box 47, 6700 AA, Wageningen, The Netherlands*
[d] *Kenya Agricultural Research Institute (KARI), PO Box 14733, Nairobi, Kenya*

Abstract

In the search for Integrated Nutrient Management practices in response to the widely observed soil fertility decline in Sub-Saharan Africa, the potential of low-external-input and organic farming remains to be systematically examined. The nutrient monitoring concept was used to assess the impact of technologies on nutrient flows and economic performance at activity and farm household level in Machakos district, Kenya. The nutrient flows and balances and economic performance indicators of farms practising low-external input agriculture (LEIA) technologies for a number of years were compared with a group of farms practising conventional farm management. Based upon monitoring two farming seasons, it was concluded that both subsistence-oriented farm management systems result in serious N-depletion and that 60–80% of farm income is based upon nutrient mining. No significant differences could be found between the LEIA and conventional farm management group. Only if LEIA farm management reduces nutrient losses through leaching and gaseous losses can a positive impact on nutrient balance be expected. Off-farm income plays a crucial role, especially in the conventional management group, in keeping farm household income levels above the poverty line. High-level compost application treatments in maize are attractive if labour and organic inputs are available. © 2001 Elsevier Science Ltd. All rights reserved.

Keywords: Kenya; Nutrient balances; Low-external-input-agriculture; Ecological and economic sustainability

* Corresponding author. Tel.: +31-70-3308341; fax: +31-70-3615624.
E-mail address: a.dejager@lei.wag-ur.nl (A. De Jager).

0308-521X/01/$ - see front matter © 2001 Elsevier Science Ltd. All rights reserved.
PII: S0308-521X(01)00020-8

1. Introduction

Exploitation of soil fertility through current farm management practices is threatening the food security and position of the economically important agricultural sector in many countries in Sub-Saharan Africa (Stoorvogel et al., 1993; Van der Pol, 1993). A number of solutions to the observed constraints have been proposed (Smaling and Braun, 1996; Mokwunye et al., 1996; Braun et al., 1997), but many of these technical options require relatively high capital investments or need a well-functioning infrastructure for effective implementation. Low economic returns to most agricultural production and existing market risks pose constraints to the use of external inputs. Alternative approaches, in the form of low-external-input agriculture (LEIA), have been developed to manage resources for agriculture to satisfy changing human needs, while maintaining or enhancing the quality of the environment and conserving natural resources. Their effectiveness is the subject of debate (Reijntjes et al., 1992; Van Reuler and Prins, 1993; Reij et al., 1996; Blaikie et al., 1997; Koning et al., 1998). Attempts are made to combine low and high input technologies in an Integrated Nutrient Management (INM) approach, aiming to maximise the use of local resources and optimise application of external inputs (Smaling et al., 1996; Pretty, 1995). In the search for INM-practices, farm management experiences of low-external input and organic farming in Sub-Saharan Africa (SSA) have not been examined systematically. There may be a high potential for LEIA farming systems in increasing both yield and sustainability of agriculture in SSA through more efficient and effective methods of nutrient management (Harris et al., 1997; Kieft, 1992; UNDP, 1992).

Adoption of the researcher developed high-external input technologies (HEIA) in SSA has been very disappointing for a variety of reasons (De Jager et al., 1998a). Two factors have played a crucial role: (1) farmers were involved only in the final stages of technology development; (2) technologies were assessed at the crop or livestock activity level only, which mostly does not match with the complex and multiple goals of a farm household at farm level. On the other hand, the experiences of LEIA technologies have not yet been fully exploited, because scientists have only recently discovered the potentials of this, often indigenous, knowledge. In an effort to increase farmers' participation and to make better use of the existing knowledge, participatory research approaches such as Participatory Technology Development (PTD; Haverkort et al., 1991; Martin and Sherington, 1997) were developed. In PTD, qualitative assessment of the available resources and farm management practices are emphasised and impacts of technologies are assessed, mainly using indicators of participating farm households.

The nutrient monitoring concept (NUTMON) adds to existing methodologies (Dalsgaard and Oficial, 1997) through integrating different knowledge systems (farmers' and scientific knowledge) and disciplines (agronomy, economics, sociology) at various scales (activity, farm, catchment/district), aiming at the assessment of the impact of technologies and policies on nutrient flows and economic performance in the agricultural sector (De Jager et al., 1998b; Van den Bosch et al., 1998). The NUTMON concept integrates the PTD approach with a more quantitative analysis. It enables, for instance, the determination and comparison of a wide range of farmers' and science-based sustainability indicators in developing INM technologies.

In this paper, NUTMON is applied in a case study of the Machakos district of Kenya, where potentials of LEIA farm management practices on the agronomic, economic and social sustainability of farming systems are assessed.

2. Methodology

2.1. Approach

The NUTMON approach distinguishes a diagnostic phase where the current situation is assessed with respect to existing natural resources, farm management and its influence on resource flows, economic performance and socio-economic environment. This is followed by an iterative and participative technology and policy development phase (De Jager et al., 1998b; Vlaming et al., 1997). In the two phases, a variety of tools are used, ranging from general PTD tools such as Participatory Rural Appraisal (PRA), natural resource flow mapping, transect walks and matrix rankings, to a specifically developed quantitative monitoring tool to assess nutrient flows and economic performance indicators. In this case study, a specific sequence of tools was applied (Fig. 1).

In order to assess the potentials of LEIA techniques, farm households applying LEIA techniques were compared with a comparable group of conventional farmers. LEIA farm households were defined as households being trained by an Non-governmental organisation (NGO) in specific LEIA farming techniques and having applied at least 3 of these techniques on more than 50% of their cultivated area over a minimum of 3 consecutive years. The comparable group of conventional farmers was defined as farm households with similar production resources to the LEIA group (Table 1) and being representative for the common farming systems characteristics in the catchment.

2.2. Model description

2.2.1. Farm conceptualisation

Farms are conceptualised as a set of dynamic units which, depending on management, form the source and/or destination of nutrient flows and economic flows. The following units are distinguished:

Farm Section Unit (FSU). Areas within the farm with relatively homogeneous properties for soil, slope and tenure characteristics.

Primary Production Unit (PPU) — crop activities. Piece of land with different possible activities such as one or more crops (annual or perennial), a pasture, a fallow or a farmyard and located in one or more FSUs.

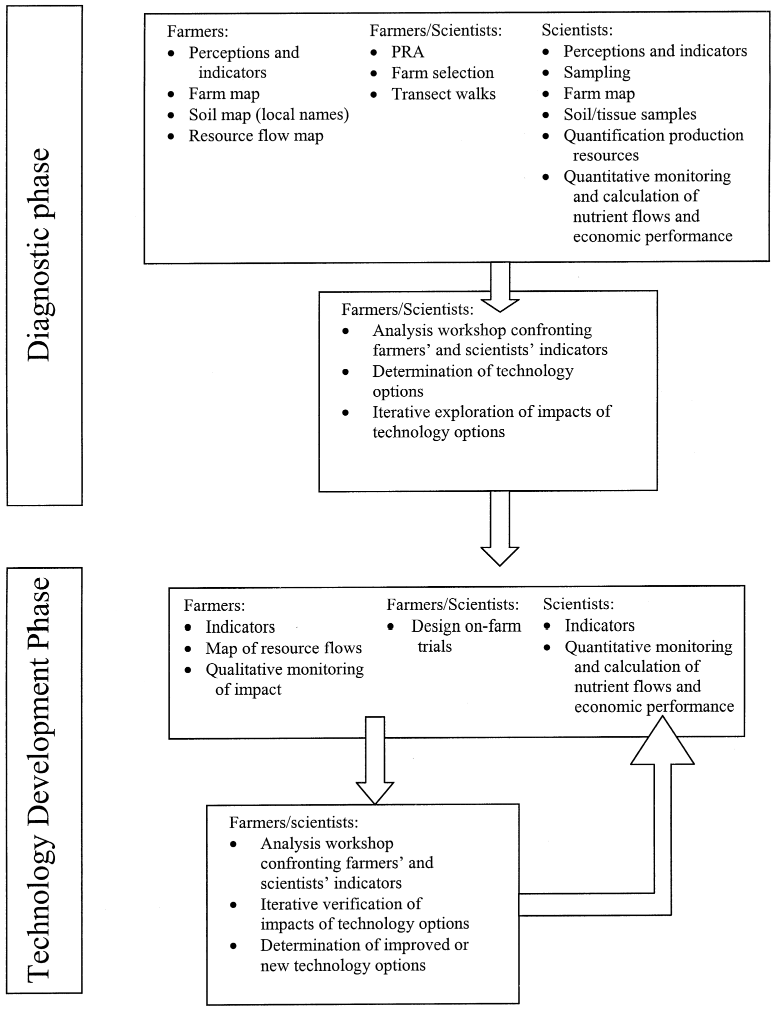


Fig. 1. Sequence of steps in NUTMON approach adopted in this study.

Secondary Production Unit (SPU) — livestock activities. A group of animals within the farm that are treated by the farm household as a single group in terms of feeding, herding and confinement. Each group generally consists of a single species.

Redistribution Unit (RU) — nutrient storage activities. Location within the farm where nutrients gather and from which they are redistributed (other than cropping activities, livestock activities and food-stock), such as manure heaps and compost pits.

Table 1
Comparison of production resources between farms with conventional and LEIA farm management practices (mean values with standard deviations in brackets)[a]

Characteristic	Conventional ($n=10$)	LEIA ($n=8$)
Labour		
Consumer units (aeu)	4.2 (2.5)	2.6 (1.1)
Labour units (aeu)	4.1 (2.3)	2.7 (1.1)
Primary education (%)[a]	92 (0.2)	94 (0.1)
Secondary education (%)[b]	42 (0.3)	42 (0.3)
Land		
Total cultivated area (ha)	2.4 (1.7)	2.4 (1.0)
Average slope (%)	17 (6.8)	17 (3.0)
N stock (kg ha^{-1})	3837 (967)	3962 (372)
P stock (kg ha^{-1})	1880 (679)	1756 (502)
K stock (kg ha^{-1})	8862 (1966)	9177 (2487)
Capital		
TLU[c]	3.3 (2.2)	3.7 (2.5)
Value of livestock (US$)[d]	570 (391)	540 (364)
Value of land (US$)	2318 (1417)	2012 (801)
Value of equipment (USbhc)	85 (76)	62 (66)
Ratios		
Land:labour (ha aeu^{-1})	0.85 (0.64)	0.95 (0.38)
Land:consumer (ha aeu^{-1})	0.85 (0.66)	1.03 (0.45)
Consumer:labour (aeu aeu^{-1})	1.02* (0.08)	0.93* (0.06)

[a] Percentage of household members older than 15 with completed primary education and more.
[b] Percentage of household members older than 15 with completed secondary education and more.
[c] TLU = tropical livestock units (1 unit is equivalent to 250 kg live weight).
[d] 1 US$ = 60 Ksh.
*Denotes significant difference ($P < 0.1$) between means from conventional and LEIA farms for a given characteristic. Significance at $P < 0.1$ was accepted because of the limited number of farms that could be involved in the research.

Household (HH). Group of people who usually live in the same house or group of houses and who share food regularly.

Stock. The amount of staple crops (cereals and pulses), crop residues (for cattle feeding) and chemical fertilizers temporarily stored for later use.

Outside (EXT). The external (nutrient) pool consisting of markets, other families and neighbours, being a source and destination at the same time which itself is not monitored.

The flows are differentiated into the following three groups:

1. Inflows: flows from an unit outside the farm to a unit within the farm (EXT → HH, PPU, SPU, RU, STOCK);

2. Outflows: flows from an unit within the farm to a unit outside the farm (HH, PPU, SPU, RU, STOCK → EXT); and
3. Internal flows: flows between units within the farm (HH, PPU, SPU, RU, STOCK ↔ HH, PPU, SPU, RU, STOCK).

The side boundaries of the farm coincide with the physical border of the farm; the upper boundary is the atmosphere–soil or atmosphere–plant interface, whereas the lower boundary is defined at 30 cm below the soil surface. Animals are considered part of the farm and depending on their location (within or outside the physical boundaries of the farm) nutrient flows are defined and calculated (Van den Bosch et al., 1998).

2.2.2. Model modules

Within the model, two modules can be distinguished: (1) one calculating nutrient flows between the units and nutrient balances for the farm, the PPUs and the RUs, and the other (2) calculating farm household characteristics and economic performance indicators at farm and activity level. The farm nutrient balance consists of six input and output flows (Fig. 2). The flows are quantified using a combination of sources such as monthly farm household interviews, transfer functions, and secondary data. In this case study, the input from sedimentation (IN5) through flooding and irrigation was of no relevance and sedimentation from erosion processes was not included because the available data did not allow such a sophisticated analysis. The input of nutrients from subsoil exploitation (IN6) was not considered because of lack of reliable data. For the determination of the nutrient balances at PPU and RU level, the sum of both internal and external flows was determined. The model consists of a set of equations calculating the various nutrient flows (Table 2).

At farm household level, economic performance indicators such as net farm income, total off-farm income, household net cash flow and returns to labour are determined. In these calculations, only the nutrient flows with an economic value attached (IN1, IN2, OUT1 and OUT2) are considered. Also, an environmental

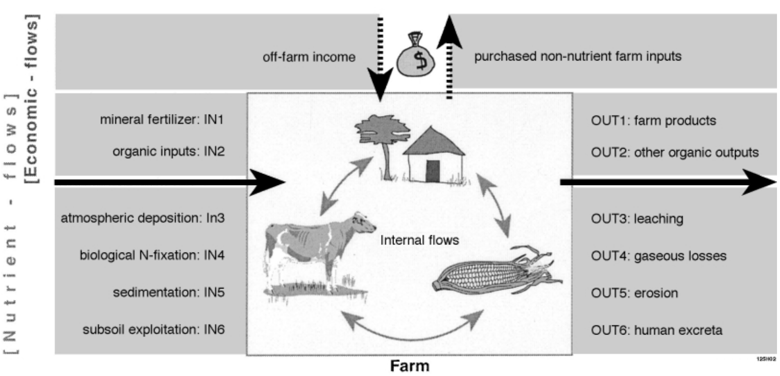


Fig. 2. Nutrient flows and economic flows influencing the nutrient balance and household budget.

Table 2
Overview of nutrient flows calculated in the NUTMON model[a]

Source (Period t)	Destination					
	EXT	HH	STOCK	$PPU_1 \ldots PPU_p$	$SPU_1 \ldots SPU_s$	$RU_1 \ldots RU_r$
EXT			$IN1.Stock_t$ $IN2.Stock_t$	$IN1.PPU_{p,t}$ $IN2.PPU_{p,t}$ $IN3.PPU_{p,t,}$ $IN4.PPU_{p,t}$	$IN1.SPU_{s,t}$ $IN2a.SPU_{s,t}$ $IN2b.SPU_{s,t}$	$IN1.RU_{r,t}$ $IN2.RU_{r,t}$
HH				$OUT2HH.IN2PPU_{p,t}$	$OUT2HH.IN2SPU_s$	$OUT2HH.IN2RU_{r,t}$
STOCK	$OUT1.Stock_t$ $OUT2.Stock_t$			$OUT1Stock.IN1PPU_{p,t}$ $OUT2Stock.IN2PPU_{p,t}$	$OUT1Stock.IN1SPU_{s,t}$ $OUT2Stock.IN2SPU_{s,t}$	$OUT1Stock.IN1RU_{r,t}$ $OUT2Stock.IN2RU_{r,t}$
$PPU_1 \ldots PPU_p$	$OUT1.PPU_{p,t}$ $OUT2.PPU_{p,t}$ $OUT3.PPU_{p,t}$ $OUT4.PPU_{p,t}$ $OUT5.PPU_{p,t}$	$OUT1PPU_{p,t}.IN1HH$ $OUT2PPU_{p,t}.IN2HH$	$OUT1PPU_{p,t}.IN1Stock$ $OUT2PPU_{p,t}.IN2Stock$	$OUT1PPU_p.IN1PPU_{p,t}$ $OUT2PPU_p.IN2PPU_{p,t}$	$OUT1PPU_p.IN1SPU_{s,t}$ $OUT2aPPU_p.IN2aSPU_{s,t}$ $OUT2bPPU_p.IN2bSPU_s$	$OUT1PPU_p.IN1RU_{r,t}$ $OUT2PPU_p.IN2RU_{r,t}$
$SPU_1 \ldots SPU_s$	$OUT1.SPU_{s,t}$ $OUT2.SPU_{s,t}$	$OUT1SPU_{s,t}.IN1HH$		$OUT2SPU_s.IN2PPU_{p,t}$	$OUT1SPU_s.IN1SPU_{s,t}$	$OUT2SPU_{s,t}.IN2RU_{r,t}$
$RU_1 \ldots RU_r$	$OUT2.RU_{r,t}$ $OUT3.RU_{r,t}$ $OUT4.RU_{r,t}$ $OUT6.RU_{r,t}$	$OUT2RU_{r,t}.IN2HH$		$OUT2RU_r.IN2PPU_{p,t}$		$OUT2RU_{r,t}.IN2RU_{r,t}$

[a] Each flow indicated in a cell refers to one or a set of equations to calculate the nutrient flow concerned; model description and software available on request. IN 1, mineral fertilisers; IN 2, organic inputs (livestock); IN 3, atmospheric deposition; IN 4, biological N-fixation; OUT 1, farm products; OUT 2, other organics; OUT 3, leaching; OUT 4, gaseous losses; OUT 5, erosion; OUT 6, human faeces; PPU, Primary Production Unit (crops); SPU, Secondary Production Unit; RU, Redistribution Unit (manure heaps etc.); HH, Household.

economic analysis is made, in which the costs of replacing the nutrients lost are valued at fertilizer prices (De Jager et al., 1998c). At activity level, gross margins and cash flows per unit are calculated, for PPUs, SPUs and RUs.

2.3. Implementation aspects

2.3.1. Sampling and farm selection

In this study, a representative catchment within the administrative district was selected. Given the logistical limitations and required monitoring frequency, a total of 18 farm households were included in the research, divided into two groups according to the criteria set for the LEIA and conventional management group. The actual selection process consisted of a workshop for the whole community aimed at discussing the objectives, creating ownership of the project and discussing criteria for participation. Farm households were selected by the community and included only after a farm visit by the NGO-staff and further discussions with the farm household members verifying the selection criteria and motivation for participation.

2.3.2. Identification of production resources

The agricultural production resources were characterised through a participatory process with the farm households identifying farm household criteria on the one hand and scientific criteria and quantitative data on the other. Participatory soil mapping was applied to identify farm households' criteria and consisted of a variety of tools such as semi-structured interviews, pair-wise and matrix ranking, transect walks, historical profiles, drawing diagrams and maps (Lightfoot et al., 1994; Diop, 1997). A structured interview, including a farm walk and soil sampling making use of the farmers' soil maps, provided a wide range of data such as demographic situation, ownership status, identification of production units, farm assets and measured soil fertility indicators (Van den Bosch et al., 1998). Comparison of farmers' and researchers' perceptions and indicators was implemented through group discussions.

2.3.3. Monitoring farm practices

A similar approach was applied to characterising farm management techniques and their impacts on nutrient flows and economic performance. Participatory tools such as participatory pictorial nutrient flow mapping (Fig. 3) were implemented. Through a monthly structured questionnaire, basic input–output data, off-farm income and prices were captured at activity level. In order to calculate nutrient flows and balances, additional data were collected to feed the transfer functions, simple models and the background database and sampling of nutrient contents of major input and output flows were conducted (Van den Bosch et al., 1998).

2.3.4. Participatory and iterative exploration of development options

During a workshop with scientists, NGO-staff and farmers, the preliminary results of the diagnostic phase were evaluated and appropriate technology options prioritised for further exploration in the PTD process.

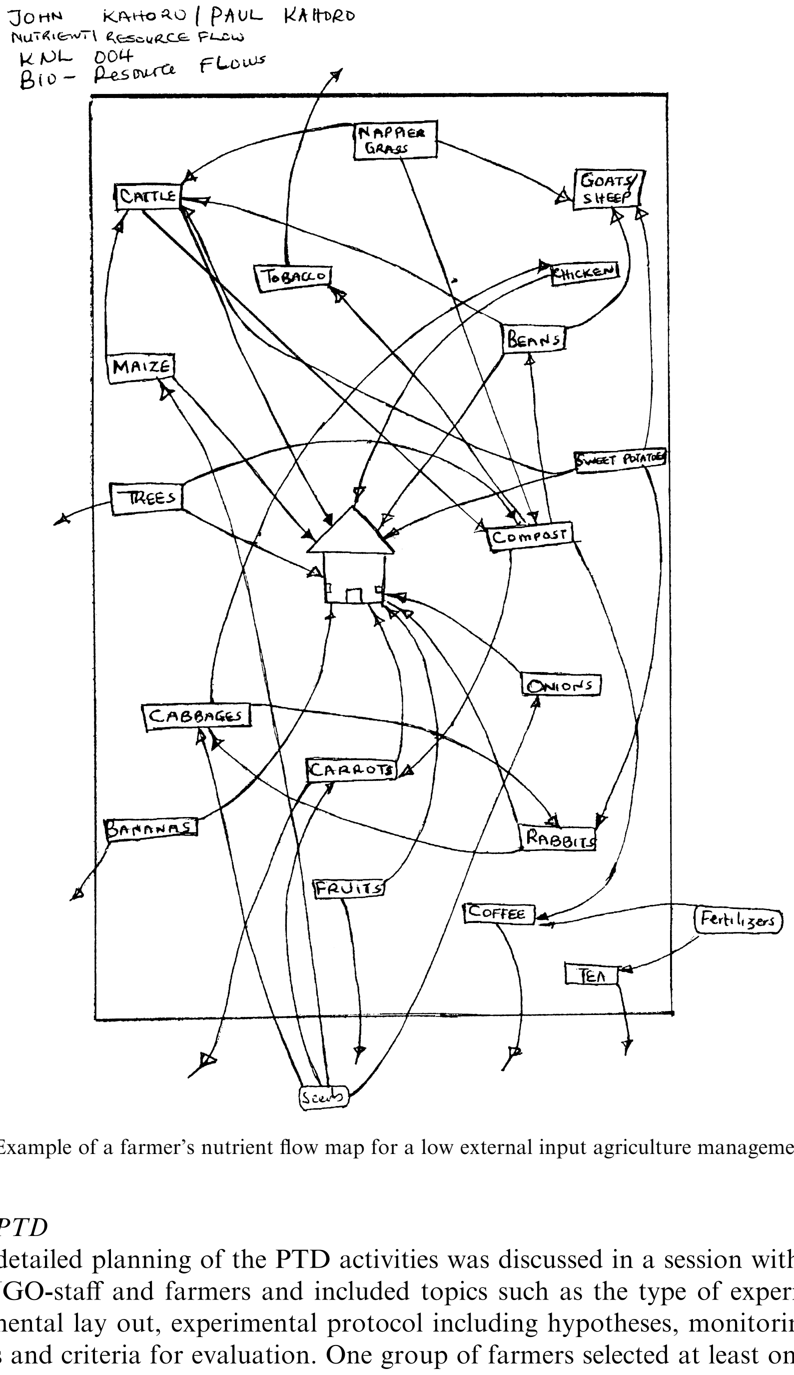


Fig. 3. Example of a farmer's nutrient flow map for a low external input agriculture management farm.

2.3.5. PTD

The detailed planning of the PTD activities was discussed in a session with scientists, NGO-staff and farmers and included topics such as the type of experiments, experimental lay out, experimental protocol including hypotheses, monitoring procedures and criteria for evaluation. One group of farmers selected at least one common experiment on their individual farms to facilitate a joint evaluation process and statistical analysis. Scientists and NGO-staff assessed the expected impact of the tested technology on the nutrient flows and economic performance in the experimental protocol and farmers drew flow maps expressing the expected changes compared to current practices. During the experiment, a field visit was organised with the farmers to visit and discuss the performance of the experiments and NGO-staff implemented a monthly monitoring of the input/output flows on the experimental plots including measurements of soil samples. After one season, a joint evaluation of the experiments was undertaken and planning for a new round of technology testing was conducted.

2.4. Area description

The Machakos district in Kenya has a low, highly variable rainfall, distributed in two rainy seasons divided by dry seasons. The soils in the region are rather shallow, generally deficient in nitrogen and phosphorus and contain little organic matter. Low infiltration rates and a susceptibility to sealing make the area's soils vulnerable to erosion, especially since most of the heavy rains occur at the beginning of the growing season when the land is still bare (Pagiola, 1996). Agriculture is the major economic sector, is subsistence-oriented and includes both crop and livestock production. Maize is the major staple crop, but a wide variety of other subsistence and cash crops are found according to changes in topography and soil type. Ranching of cattle, sheep and goats is the major livestock production system, while in a few high potential areas intensive zero-grazing systems exist. One of the major problems encountered is declining soil fertility in already fragile soils resulting in low agricultural productivity and deteriorating production resources. The high population pressure in the area, which has contributed to an increase in soil conservation investments (Tiffen et al., 1994), forces farmers to follow a strategy of intensification of the production systems. Since increased use of external inputs is not feasible given the subsistence orientation and the low economic returns in the current socio-economic environment, other options to increase the sustainability of the farming systems need to be explored. The Kenyan Institute of Organic Farming is a Kenyan-based NGO, which has been training groups of farmers in organic farming techniques in Machakos and other regions for over 10 years, resulting in groups of farmers practising LEIA and organic farming techniques for a number of years.

3. Results

3.1. Impact of LEIA on resource flows and economic performance

At the beginning of the research, a distinct difference in farm management practices between the two farm management groups existed. In the conventional farm management group, LEIA practices such as composting, double digging and application of natural pesticides were hardly practised, while in the LEIA group these practices were applied on 100, 75 and 75% of farms in the sample group respectively (Table 3). However, under the influence of the project and the regular visits and

Table 3
Application levels of LEIA farming techniques and preference matrix rankings between farms with conventional and LEIA farm management

Soil fertility management practice	% Farmers applying			Preference ranking	
	Conventional Year 1	Conventional Year 2	LEIA Year 2	Conventional Year 2	LEIA Year 2
Short term practices					
Composting	10	100	100	1.2	1.0
Intercropping	90	90	88	2.1	2.8
Crop rotation	80	80	100	1.7	3.5
Double digging	0	20	75	3.3	3.7
Deep digging	0	30	50	2.5	3.8
Natural pesticides	0	20	75	3.0	4.6
Tree nurseries	10	10	63	–	6.0
Liquid manure	0	0	63	5.0	6.5
Long term practices					
Fanya yuu (terracing)	100	100	–	–	
Cut-off drains	42	42	37	–	–

meetings, farmers in the conventional group gradually started to change their management and in the second year all farms in the conventional group had adopted composting practices to varying degrees (Table 3). In the second year, differences still existed in application of a number of specific techniques such as double digging, use of natural pesticides and liquid manure. In the following discussion, the analysis of the farming systems of the two management groups is based on the first year only, when there were still major differences between the two management groups.

No differences in the role of trees and shrubs between the two farm management groups were observed. On average, farm households had between 120–150 trees and shrubs per ha and between 30–35 tall trees per ha on the farm either as borders or integrated within the cropping system (Table 4). Firewood was the major use of trees, but charcoal making, fencing, fruits, medicinal products and green manure were also important.

The farmers' nutrient flow maps showed that conventional farms had a slightly higher number of different in-flows than the LEIA group (Table 5). The number of different out- and internal flows were considerably higher in the LEIA group, due to a higher degree of diversification of crops cultivated and the fact that manure was more often used on LEIA farms than on conventional farms.

For both conventional and LEIA farm management, negative balances were found for N of, respectively, 53 and 56 kg ha^{-1} $year^{-1}$ and for K of, respectively, 9 and 12 kg ha^{-1} $year^{-1}$, while P was fairly well in balance in both cases (Table 6). The average partial balances for N and K, consisting of the nutrient flows in direct farm inputs and product outputs (IN1 + IN2−OUT1−OUT2−OUT6), were reasonably well balanced with −5 and −3 kg ha^{-1} $year^{-1}$ for N and + 1 and −2 kg ha^{-1} $year^{-1}$ for K. Farmers apparently import as much N and K as is exported through crop

Table 4
The role of trees in LEIA and conventional farm management systems (mean values with standard deviations in brackets)[a]

	Conventional ($n=10$)	LEIA ($n=8$)
Total number of trees and shrubs (number ha^{-1})	158 (137)	120 (91)
Total number of trees (> 2 m) (number ha^{-1})	34 (38)	31 (26)
Total different number of species	11 (6)	12 (5)
Uses (average frequency per tree species per FSU)		
Firewood	17 (7)	15 (5)
Charcoal	8 (4)	6 (3)
Fencing	8 (3)	7 (2)
Live fencing	1 (1)	1 (1)
Building material	1 (2)	2 (2)
Fodder	7 (3)	5 (3)
Compost/green manure	7 (3)	5 (2)
Fruits	7 (4)	8 (5)
Medicinal or others	6 (2)	5 (2)

[a] FSU, farm section unit; see text for definition.

products and residues, but leaching (N and K) and gaseous losses (N) result in total balances becoming negative. Especially for nitrogen, both management systems appear to be unsustainable: the current management leads to a 50% reduction of the available N-stock in 35 (linear annual reduction with 55 kg of N) to 50 years (annual percentage reduction of N-stock with 1.4%). However, since the specific impacts of LEIA technologies on leaching, gaseous losses and erosion could not be included due to absence of relevant data, the balances of the LEIA systems may turn out to be slightly more positive.

The internal flows between the two management systems also showed no major differences (Table 7). Although the farmers' nutrient flow maps showed an increased use of manure in the LEIA group, in the quantitative monitoring of this flow, redistribution from the RU to the PPU, was completely lacking in both farming systems. According to the field staff, the weather conditions during the monitoring season with extreme dry conditions in the first and extreme wet conditions in the second season made farmers reluctant to apply their valuable manure. Observations in the second year, where farmers widely applied manure and compost, seem to support this explanation.

Although not statistically significant, the various economic performance indicators tend to indicate higher levels for LEIA farm management compared to conventional management (Table 8). Also, returns to labour were higher, despite higher labour input in LEIA management. The off-farm income levels were higher in the conventional group, resulting in higher total family earnings between the two management groups. The family earnings per adult equivalent unit (aeu) were, however, comparable. The subsistence-oriented systems (low market orientation in both cases) realised rather low returns to labour compared to the average wages for unskilled labour of US$ 1.5 per day. LEIA farm management realised good

Table 5
Mean number of total nutrient flows per farm and per type of flow identified by farm households in conventional and LEIA farm management systems (standard deviations in brackets)[a]

Type of flow	Conventional ($n = 10$)	LEIA ($n = 8$)
In-flows	3.2 (2.2)	2.8 (2.0)
Out-flows	5.6 (1.7)	9.3 (1.8)
Internal flows	19.9 (3.3)	26.0 (7.2)
Specified internal flows		
PPU→SPU	4.5 (1.3)	4.3 (1.4)
SPU→PPU	0.4 (1.3)	0.0 (–)
PPU→RU	0.0 (–)	0.0 (–)
RU→PPU	1.5 (1.2)	3.2 (1.7)
SPU→RU	2.3 (1.1)	3.3 (0.5)
RU→SPU	0.0 (–)	0.0 (–)
PPU→HH	8.8 (2.7)	12.2 (4.6)
HH→PPU	0.0 (–)	0.0 (–)
SPU→HH	2.2 (0.6)	2.7 (0.8)
HH→SPU	0.0 (–)	0.0 (–)
RU→HH	0.0 (–)	0.0 (–)
HH→RU	0.2 (0.4)	0.3 (0.5)

[a] PPU, Primary Production Unit (crops); SPU, Secondary Production Unit (livestock); RU, Redistribution Unit (manure heap etc.); HH, Household.

Table 6
Soil nutrient balances for conventional and LEIA farm management systems (mean values with standard deviations in brackets)

Nutrient flow	N (kg ha^{-1})		P (kg ha^{-1})		K (kg ha^{-1})	
	Conventional	LEIA	Conventional	LEIA	Conventional	LEIA
Farm balance	−53 (18)	−56 (22)	1 (6)	−1 (3)	−9 (10)	−12 (12)
IN 1 (fertilisers)	6* (6)	2* (4)	5 (6)	2 (3)	0 (0)	0 (0)
IN 2 (organic inputs)	5 (8)	6 (7)	1 (2)	2 (2)	4 (7)	4 (5)
IN 3 (atmospheric deposition)	5 (0)	5 (0)	1 (0)	1 (0)	3 (0)	3 (0)
IN 4 (biological N-fixation)	7 (5)	8 (5)	0 (0)	0 (0)	0 (0)	0 (0)
OUT 1 (farm products)	−2 (2)	−1 (2)	−0 (1)	−0 (0)	−1 (1)	−1 (2)
OUT 2 (other organics)	−0 (1)	−4 (5)	−0 (0)	−1 (2)	−0 (1)	−4 (4)
OUT 3 (leaching)	−36 (5)	−36 (10)	−0 (0)	−0 (0)	−5 (3)	−8 (8)
OUT 4 (gaseous losses)	−19 (5)	−25 (11)	−0 (0)	−0 (0)	−0 (0)	−0 (0)
OUT 5 (erosion)	−5 (7)	−2 (1)	−2 (2)	−1 (1)	−7 (10)	−4 (3)
OUT 6 (human faeces)	−14* (19)	−6* (2)	−4* (5)	−2* (1)	−2 (3)	−1 (0)

*Denotes significant difference ($P < 0.1$) between means from conventional and LEIA farms for a given nutrient flow. Significance at $P < 0.1$ was accepted because of the limited number of farms that could be involved in the research.

Table 7
Matrix of mean realised N-flows (kg ha^{-1}) for (a) conventional and (b) LEIA farm management systems (standard deviation in brackets)[a]

Source	Destination					
	Ext	PPU	SPU	RU	HH	Stock
(a) Conventional farm management N-flows (kg N ha^{-1})						
Ext		6 (6)	3 (4)	0 (1)		4 (7)
PPU	1 (1)	0 (0)	73 (0)	0 (0)	4 (5)	3 (2)
SPU	0 (0)	21 (11)	0 (0)	21 (9)	0 (0)	0 (0)
RU	0 (0)	2 (16)		0 (0)		
HH		0 (0)	0 (0)	14 (20)		
Stock	1 (2)	0 (0)	0 (0)	0 (0)		
(b) LEIA farm management N-flows (kg N ha^{-1})						
Ext		3 (4)	18 (21)	0 (0)		2 (3)
PPU	0 (1)	0 (0)	84 (64)	0 (0)	5 (4)	4 (3)
SPU	4 (5)	22 (14)	0 (0)	27 (18)	0 (0)	0 (0)
RU	0 (0)	1 (1)		0 (1)		
HH		0 (0)	0 (0)	6 (2)		
Stock	1 (1)	0 (0)	1 (3)	0 (0)		

[a] PPU, Primary Production Unit (crops); SPU, Secondary Production Unit (livestock); RU, Redistribution Unit (manure heap etc.); HH, Household.

returns to land, which are comparable to the average land rent in the district of US$ 55 ha^{-1} $year^{-1}$.

Applying replacement cost methodology, it appeared that in conventional farm management 80% of the income was based upon nutrient mining against 60% in LEIA management. The comparable negative balances and the higher realised income levels on LEIA farms explained this difference. It appeared that in both systems farm families live well above the estimated poverty line of US$ 182 per aeu per year (World Bank, 1995; De Jager et al., 1998c), but that off-farm income, especially on the conventional farms, was the main source of income.

An example of the results at activity level is presented in Table 9 for the common maize–bean intercropping system. No significant differences in the main performance indicators between the management groups were found. However, slightly less negative nutrient balances were found in the conventional group, mainly due to higher inputs from inorganic and organic fertilisers.

3.2. Impact of technology options

During the farmers' experimentation design workshop, the following technologies were prioritised:

1. preparation and utilisation of organic fertilisers;
2. use of a combination of organic and inorganic fertilisers;
3. manure and fertiliser application rates.

Table 8
Economic performance indicators for conventional and LEIA farm management systems (mean values with standard deviations in brackets)[a]

	Conventional ($n = 10$)	LEIA ($n = 8$)
Net farm income (US\$ year^{-1})	334 (319)	538 (523)
Net farm income (US\$ ha^{-1} year^{-1})	138 (111)	201 (133)
Share of crops (% of net farm income)	78 (22)	88 (12)
Market orientation (% of gross value sold)	14 (16)	13 (20)
Off-farm income (US\$ year^{-1})	1022 (1483)	311 (205)
Family earnings (US\$ year^{-1})	1356 (1354)	850 (669)
Family earnings (US\$ aeq^{-1})	397 (368)	376 (357)
Household net cash flow (US\$ year^{-1})	940 (1401)	391 (619)
Replacement costs (US\$ year^{-1})	291 (180)	291 (154)
Replacement costs (US\$ ha^{-1} year^{-1})	110 (45)	121 (50)
Family labour PPU (days)	277 (106)	327 (162)
Family labour SPU (days)	155 (58)	148 (39)
Family labour general (days)	88 (34)	101 (38)
Off-farm labour (days)	169 (222)	78 (107)
Hired labour PPU (days)	18 (38)	18 (27)
Hired labour SPU (days)	0 (0)	16 (44)
Return to labour (US\$ day^{-1})	0.1 (0.5)	0.5 (1.0)
Return to land (US\$ ha^{-1})	−0.5 (121)	52 (174)
Gross margin PPU (US\$ day^{-1})	1.6 (1.1)	2.4 (1.9)
Gross margin SPU (US\$ day^{-1})	0.6 (0.9)	0.4 (1.4)

[a] NFI, Net Farm Income; PPU, Primary Production Unit (crops); SPU, Secondary Production Unit (livestock).

Through consensus the group decided on the following treatments on the test crop maize (indigenous variety) on plots of 9×5 m:

1. normal practice (T1): for LEIA farmers, 0.5 kg tin of compost per planting hole (16 MT ha^{-1}) + normal tillage; for conventional farmers, 0.5 kg of manure per planting hole (17 MT ha^{-1}) and 57 kg ha^{-1} diammonium phosphate;
2. 1 kg tin of compost per planting hole (33 MT ha^{-1}) + normal tillage (T2);
3. 1 kg tin of compost per planting hole (33 MT ha^{-1}) + liquid manure (7 MT ha^{-1}) + normal tillage (T3).

Liquid manure is a fast working fertiliser and is developed by the Kenya Institute of Organic Farming as a technique to have an alternative for fast working fertilisers such as CAN ($Ca(NO_3)_2$). Manure with easily soluble nutrients such as chicken or rabbit manure is placed in a permeable bag, which is placed in a drum or container filled with water. After 3 weeks with regular stirring, the manure is ready for application.

According to the farmers' assessment of the first season (Table 10), the two tested technologies scored higher in terms of productivity, soil improvement and economic

Table 9
Mean yields, nutrient balances and economic performance of maize-bean intercropping in conventional and LEIA farm management (standard deviation in brackets)

	Conventional ($n=11$)	LEIA ($n=9$)
Yield maize (kg ha^{-1})	399 (650)	224 (534)
beans (kg ha^{-1})	687 (1498)	713 (1064)
Gross value (US$ ha^{-1})	547 (1069)	494 (775)
Variable costs (US$ ha^{-1})	244 (647)	13 (15)
Gross Margin (US$ ha^{-1})	303 (540)	481 (779)
N-balance	−28 (38)	−39 (37)
P-balance	1 (11)	−4 (12)
K-balance	−9 (55)	−27 (40)
N detailed flows		
IN 1 (fertilizers)	6 (8)	2 (5)
IN 2 (organic inputs)	25 (82)	0 (0)
IN 3 (atmospheric deposition)	3 (1)	2 (1)
IN 4 (biological N-fixation)	23 (44)	19 (27)
OUT 1 (farm products)	−23 (44)	−20 (32)
OUT 2 (other organics)	−32 (60)	−21 (33)
OUT 3 (leaching)	−19 (17)	−13 (4)
OUT 4 (gaseous losses)	−7 (8)	−6 (2)
OUT 5 (erosion)	−3 (5)	−1 (1)

Table 10
Farmers' assessment of PTD trials in maize on farms with conventional and LEIA farm management (10 points were distributed over the three treatments)[a]

Criteria	Indicator	LEIA ($n=8$)			Conventional ($n=10$)		
		T1	T2	T3	T1	T2	T3
Productivity	Yield	2.0	3.4	4.6	2.6	2.6	4.8
	Seed quality	3.3	3.7	3.0	2.9	3.6	3.6
Soil improvement	Soil fertility	2.0	3.7	4.3	1.9	3.1	5.0
	Soil structure	2.3	3.1	4.6	2.1	3.1	4.9
	Incidence of weeds	2.0	3.1	4.9	2.2	2.8	4.7
	Quality of compost	1.9	3.4	4.7	2.0	3.3	4.6
Economic benefits	Money saving	2.9	3.0	4.1	2.1	3.1	4.7
Labour	Labour input	2.0	3.1	4.9	2.6	2.7	4.7
Vigorous and strong crops	Vigour	2.0	3.4	4.6	4.2	2.4	3.6
	Leaf colour	2.0	3.0	5.0	3.6	2.3	4.1
Pest control/crop protection	Incidence of pests/diseases	4.4	2.9	2.7	3.1	3.1	3.9

[a] T1, LEIA: 16 MT ha^{-1} compost manure; Conventional: 17 MT ha^{-1} manure + 57 kg ha^{-1} diammonium phosphate; T2, 33 MT ha^{-1} compost; T3, 33 MT ha^{-1} compost + 7 MT ha^{-1} liquid manure.

benefits, while also increasing labour requirements. These observations correspond largely with the quantitative observations of the scientist (Table 11). The gross margin per unit area increased with higher application rates of compost and liquid manure: +13% for T2 over T1 and +19% for T3 over T1 on conventional farms.

Table 11
Impact of tested technologies in maize on economic characteristics and nutrient balances at activity level for conventional and LEIA farm management (mean values with standard deviations in brackets)[a]

	Conventional ($n=10$)			LEIA ($n=8$)		
	T1	T2	T3	T1	T2	T3
Yield grains (MT ha^{-1})	2.4 (1.2)	3.0 (1.7)	3.3 (1.6)	2.8 (3.0)	3.1 (2.5)	3.9 (3.2)
Yield stover (MT ha^{-1})	7.3 (4.3)	7.8 (5.2)	8.8 (4.7)	7.1 (2.3)	7.9 (2.3)	9.0 (2.0)
Labour (days ha^{-1})	92 (27)	99 (27)	162* (55)	103 (28)	108 (45)	175* (51)
Gross margin (US$ ha^{-1})	373 (322)	420 (423)	443 (361)	452 (444)	432 (368)	508 (489)
Variable costs (US$ ha^{-1})	257* (30)	316* (49)	380* (84)	223 (42)	331* (92)	422* (91)
Gross margin (US$ day^{-1})	4.4 (3.7)	4.3 (4.0)	2.7 (2.4)	4.4 (3.4)	4.4 (3.4)	3.2 (3.2)
Partial N-balance (kg ha^{-1})	−56	−49	−54	−74	−54	−63
Partial P-balance (kg ha^{-1})	1	−9	−10	−14	−9	−12

[a] T1, LEIA: 16 MT ha^{-1} compost manure; Conventional: 17 MT ha^{-1} manure + 57 kg ha^{-1} diammonium phosphate; T2, 33 MT ha^{-1} compost; T3, 33 MT ha^{-1} compost + 7 MT ha^{-1} liquid manure.

*Denotes significant difference ($P < 0.1$) between treatment means within farm management types (conventional and LEIA).

On the farms with LEIA management, lower increases were found: +12% for T3 over T1. But due to the increased labour input with higher application levels, the gross margin per labour day was reduced: −34% for T3 compared to T1 in the conventional and LEIA management group. None of these observed differences were statistically significant, due to the high between farm variation. Limited impact of the treatments on the negative N-balance was observed, since the higher yield levels resulted in an increased export of nutrients from the plots. In discussion with farmers, it appeared that only annual application on part of the farm was considered feasible (plot treatment once every 3–5 years). It is, therefore, important to monitor the residual effect of these treatments before a full assessment of the potentials of these technologies can be made.

Based upon monitoring two farming seasons, it is concluded that both subsistence-oriented farm management systems result in serious N-depletion and that 60–80% of farm income is based upon nutrient mining. No significant differences could be found between the LEIA and conventional farm management group. Only if LEIA farm management reduces nutrient losses through leaching and gaseous losses can a positive impact on the nutrient balance be expected. When the relationships between specific LEIA techniques and these losses can be quantified, a more specific assessment can be made. The economic performance appeared to be higher in the LEIA farm management group, although with the small sample size no significant differences were found. Off-farm income played a crucial role, especially in the conventional management group, in keeping the farm household income levels above the poverty line. The high-level compost application treatments in maize have potential, although the labour input and availability of material for producing good quality compost are serious limiting factors.

4. Discussion and conclusion

Although not all aspects of the NUTMON approach have yet been implemented, the multi-disciplinary, participatory, qualitative and quantitative approach to assess and develop farming systems yielded very promising results. The approach appeared to be an effective instrument to have researchers and farmers join forces in analysing the current system and developing new appropriate alternatives. On the other hand, the quantified nutrient flows and economic performance indicators provide essential inputs in scenario studies and play a role in placing soil fertility and sustainability issues on the agenda of policy makers. A number of specific activities involving policy makers are yet to be implemented and appropriate tools and approaches to facilitate this have yet to be developed.

It is observed that for the process of participatory technology development at farm level alone, a detailed diagnostic phase as implemented in this approach is somewhat superfluous. The major priorities could also have been determined using only participatory and qualitative approaches. However the major advantages of such an intensive diagnostics phase is that attempts are made to address the impact on difficult-to-quantify flows and that data become available through which the sustainability aspects of current farm management practices can be assessed and compared with other systems elsewhere.

A number of issues in the approach still need further development. The hard-to-quantify flows need a more accurate and site specific approach and understanding the impacts on these flows of farm management techniques is essential to arrive at a comprehensive analysis of the full nutrient balance. A better insight is still required on the dynamic aspects of nutrient flows, nutrient stocks and their relation to crop yields. In order to present reliable sustainability indicators and more accurate economic impact calculations, future yield development given specific nutrient balance and nutrient stock levels need to be determined. The currently applied replacement cost method is rather inaccurate and does not allow for a dynamic impact assessment over a period of time. Since livestock play an important role in nutrient management in most farming systems in SSA, more detailed knowledge is required on aspects such as quality of manure in relation to feed uptake, nutrient losses in processes of manure storage and composting, and excretion quantities during various activities of livestock divided over the day.

In order to better guide the process of analysis and to explore possible technical and policy options both with farm households and policy makers during diagnostic workshops, tools need to be developed to integrate the large amount of available information and enable 'what-if' type calculations to explore various options and assumptions. Depending on the type and depth of the analysis required, the complexity of such an instrument may vary, but in all cases it should be transparent to the users.

Acknowledgements

The European Union and Dutch Ministry of Agriculture, Fisheries and Nature Management are gratefully acknowledged for supporting this research.

References

Blaikie, P., Brown, K., Stocking, M., Tang, L., Dixon, P., Sillitoe, P., 1997. Knowledge in action: local knowledge as a development resource and barriers to its incorporation in natural resource research and development. Agricultural Systems 55 (2), 217–237.

Braun, A.R., Smaling, E.M.A., Muchugu, E.I., Shepherd, K.D., Corbett, J.D., 1997. Maintenance and Improvement of Soil Productivity in the Highlands of Ethiopia, Kenya, Madagascar and Uganda: an Inventory of Spatial and Non-Spatial Survey and Research Data on Natural Resources and Land Productivity (African Highland Initiative Technical Report Series No. 6). ICRAF, Nairobi, Kenya.

Dalsgaard, J.P.T., Oficial, R.T., 1997. A quantitative approach for assessing the productive performance and ecological contributions of smallholder farms. Agricultural Systems 55 (4), 503–533.

De Jager, A., Mokwunye, A.U., Smaling, E.M.A. 1998a. Do fertilizers play a major role in sustainable agricultural development in West Africa? In: Wossink, G.A.A., van Kooten, G.C., Peters, G.H. (Eds.), Economics of Agro-Chemicals: An International Overview of Use Patterns, Technical and Institutional Determinants, Policies and Perspectives. Selected papers of the conference of the IAAE held at Wageningen, 24–28 April 1996. Dartmouth, Aldershot, UK.

De Jager, A., Nandwa, S.M., Okoth, P.F., 1998b. Monitoring nutrient flows and economic performance in African farming systems (NUTMON). I. Conceptual framework. Agriculture, Ecosystems and Environment 71 (1–3), 37–48.

De Jager, A., Kariuki, F.M., Matiri, M., Odendo, M., Wanyama, J.M., 1998c. Monitoring nutrient flows and economic performance in African farming systems (NUTMON). IV. Monitoring of farm economic performance in three districts in Kenya. Agriculture, Ecosystems and Environment 71 (1–3), 81–92.

Diop, J.M., 1997. Participatory soil mapping and participatory pictorial bioresource/nutrient flows: reader compiled to support theoretical and practical training. Internal project document.

Harris, P.J.C., Lloyd, H.D., Hofny-Collins, A.H., Barrett, H.R., Browne, A.W., 1997. Organic Agriculture in Sub-Saharan Africa: Farmer Demand and Potential for Development, a Study to Inform Policy. Henry Doubleday Research Association, Coventry.

Haverkort, B., Van der Kamp, J., Waters-Bayer, A., 1991. Joining Farmers' Experiments: Experiences in Participatory Technology Development. ITP, London.

Kieft, H., 1992. The future of LEISA in Sub-Saharan Africa. In: Sustainable Development in Semi-Arid Sub-Saharan Africa. Ministry of Foreign Affairs, The Hague, The Netherlands.

Koning, N., Heerink, N., Kauffman, S., 1998. Integrated soil improvement and agricultural development in West Africa: why current policy approaches fail. Wageningen Economic Papers volume 9, 9–98.

Lightfoot, C., Prein, M., Lopez, T., 1994. Bioresource flow modelling with farmers. ILEIA newsletter October 1994.

Martin, A., Sherington, J., 1997. Participatory research methods — implementation, effectiveness and institutional context. Agricultural Systems 55 (2), 195–216.

Mokwunye A.U., De Jager, A., Smaling, E.M.A. (1996) Restoring and Maintaining the Productivity of West African Soils: Key to Sustainable Development. IFDC miscellaneous studies No. 9, Lome, Togo.

Pagiola, S., 1996. Price policy and returns to soil conservation in semi-arid Kenya. Environmental and Resource Economics 8, 255–271.

Pretty, J.N., 1995. Regenerating Agriculture: Policies and Practice for Sustainability and Self-reliance. Earthscan, London, UK.

Reij, C., Scoones, I., Toulmin, C., 1996. Sustaining the Soil: Indigenous Soil and Water Conservation in Africa. Earthscan, London, UK.

Reijntjes, C., Haverkort, B., Waters-Bayer, A., 1992. Farming for the Future: An Introduction to Low-External-Input and Sustainable Agriculture. ILEIA, Leusden, The Netherlands.

Smaling, E.M.A., Braun, A.R., 1996. Soil fertility research in Sub-Saharan Africa: new dimensions, new challenges. Communications in Soil Science and Plant Analysi 27 (3–4), 365–386.

Smaling, E.M.A., Fresco, L.O., De Jager, A., 1996. Classifying and monitoring soil nutrient stocks and flows in African agriculture. Ambio 25, 492–496.

Stoorvogel, J.J., Smaling, E.M.A, Janssen, B.H., 1993. Calculating soil nutrient balances at different scale. I. Supra-national scale. Fertilizer Research 35, 227–235.

Tiffen, M., Mortimore, M., Gichuki, F., 1994. More People, Less Erosion: Environmental Recovery in Kenya. Wiley, Chichester.

UNDP, 1992. Benefits of Diversity. UNDP, New York.

Van den Bosch, H., De Jager, A., Vlaming, J., 1998. Monitoring nutrient flows and economic performance in African farming systems (NUTMON). II. Tool development. Agriculture, EcosystEms and Environment 71 (1–3), 49–62.

Van der Pol, F., 1993. Analysis and evaluation of options for sustainable agriculture, with special reference to southern Mali, In: Van Reuler, H., Prins, W.H. (Eds.), The Role of Plant Nutrients for Sustainable Food Crop Production in Sub Saharan Africa. VKP, Leidschendam 69–88.

Van Reuler, H., Prins, W.H., 1993. The Role of Plant Nutrients for Sustainable Food Crop Production in Sub-Saharan Africa. VKP, Leidschendam.

Vlaming, J., Gitari, J.N., Van Wijk, M.S., 1997. Farmers and researchers on their way to Integrated Nutrient Management. ILEIA Newsletter 13,(3), 6–8.

World Bank, 1995. Kenya Poverty Assessment. Population and Human Resources Division, Africa Region, Washington, DC.

Chapter 6 Potentials of low-external-input technologies in 4 different agro-ecological zones in Kenya and Uganda

De Jager, A., Onduru, D.D., Walaga, C., 2004.

Facilitated learning in soil fertility management: assessing potentials of low-external-input technologies.

Agricultural Systems 79: 205-223.

Available online at www.sciencedirect.com
SCIENCE DIRECT

AGRICULTURAL SYSTEMS

ELSEVIER

Agricultural Systems 79 (2004) 205–223

www.elsevier.com/locate/agsy

Facilitated learning in soil fertility management: assessing potentials of low-external-input technologies in east African farming systems

A. de Jager[a,*], D. Onduru[b], C. Walaga[c]

[a] *Agricultural Economics Research Institute (LEI), PO Box 29703, 2502LS Den Haag, The Netherlands*
[b] *ETC-East Africa, PO Box 76378, Nairobi, Kenya*
[c] *Environmental Alert, PO Box 11259, Kampala, Uganda*

Received 2 May 2002; received in revised form 1 April 2003; accepted 22 April 2003

Abstract

The paper describes the facilitated learning process of farm households and district policy makers in addressing the problem of soil nutrient depletion. The process is applied in a case study in four districts in Kenya and Uganda during the period 1997–1999, where the potentials of low-external input technologies (LEIA) in addressing the soil nutrient depletion problem were assessed. Working through an inclusive process of dialogue, observation, diagnosis, experimentation and exposure to different types of knowledge, participants made a thorough analysis of the current soil fertility situation and tested various LEIA options for improving soil fertility management. In all four research sites the future agricultural productivity is threatened by soil nutrient depletion. Maximal use of locally available nutrients through LEIA techniques, combined with optimal use of external nutrients appears to be the most appropriate strategy in the existing economic environment. Long-term and intensive collaboration between research institutions on the one hand and extension services, non-government and community based organisations on the other are a prerequisite for a successful and sustainable implementation of a facilitated learning approach. Involvement of stakeholders in the various stages of the research process, including the planning and project formulation is essential for an effective follow-up and implementation of the results. More attention needs to be paid to the development of communication tools to enable an effective interaction between policy makers and researchers.
© 2003 Elsevier Ltd. All rights reserved.

Keywords: Participatory technology development; Facilitated learning; Soil fertility; Nutrient management; East Africa

* Corresponding author. Tel.: +31-70-335-8341; fax: +31-70-361-5624.
E-mail address: andre.dejager@wur.nl (A. De Jager).

0308-521X/03/$ - see front matter © 2003 Elsevier Ltd. All rights reserved.
doi:10.1016/S0308-521X(03)00071-4

1. Introduction

The number of people falling below the poverty line of US$1/day is estimated above 1.3 billion in the whole world and is still increasing, especially in Sub-Saharan Africa (SSA) rendering most of them food insecure. Many studies and workshops have addressed this issue and tried to identify the major causes and to develop strategies alleviating poverty and food insecurity (McCulloch et al., 1999). A world-wide consultation of relevant stakeholders conducted by IFPRI resulted in a number of emerging issues for food policy research for developing countries (Pinstrup-Andersen, 2000). The continued degradation of the natural resource base is, together with other aspects such as the partly negative impacts of increasing globalisation, the slow technology revolution, the changing role of the state and importance of good governance, the imperfect functioning of agricultural input and output markets, and processes of population increase and urbanisation considered as being a major constraint to achieve the necessary productivity increases in the future. Various publications have addressed the magnitude of resource degradation (Stoorvogel et al., 1993; Van der Pol, 1993; Scherr, 1999; Smaling et al., 1999), and technical solutions to the observed constraints have been proposed (Smaling and Braun, 1996; Mokwunye et al., 1996; Braun et al., 1997). So far impacts have been rather limited since many of these technical options require relatively high capital investments, need a well-functioning infrastructure and a conducive policy and market environment, all of which are constraining factors in most of SSA.

In one response to the low success rate, the research community and development organisations started to shift its focus to developing low external input technologies (LEIA). The effectiveness and impacts of these approaches have been subject of debate. Research results, mostly in the form of case studies, and practical NGO experiences have shown success stories with implementation of LEIA techniques (Reij et al., 1996; Reij and Waters Bayer, 2002). Other authors advocate the inadequacy of these solutions given the growing population and related need for food and economic growth and development (Van Reuler and Prins, 1993; Koning et al., 1998) or describe the limitations (Blaikie et al., 1997). Another line of thought attempts to combine low and high input technologies in an Integrated Nutrient Management (INM) approach, which attempts to maximise the use of local resources and optimise application of external inputs (Smaling et al., 1996; Pretty, 1995). In the search for INM-practices, experiences of low-external input and organic farming at farm-level in SSA have hardly been examined systematically.

The lack of participation of principal stakeholders, such as farm households and policy makers, in technology development processes is considered as another major limitation to success (Defoer et al., 2000; Smaling et al., 2002). Technical options often prove inappropriate for the complex environment of farm households, which have to satisfy multiple goals and are often forced to focus on a short-term planning horizon. Policy makers also have multiple goals and rarely focus on agriculture or natural resource degradation alone. Involving policy makers in the development of the research process is essential to create awareness of the problems of natural resource degradation, to focus research on the needs of the policy makers and to establish linkages between technologies and related required facilitating policies (Scoones, 2001).

The purpose of this paper is to describe and assess the facilitated learning process of farm households and district policy makers in addressing the problem of soil nutrient depletion. The process is applied in a case study where the potentials of low-external input technologies in addressing the soil nutrient depletion problem are assessed. The case study is based upon the experiences and results of a project in four districts in Kenya and Uganda during the period 1997–1999.

2. Methodology

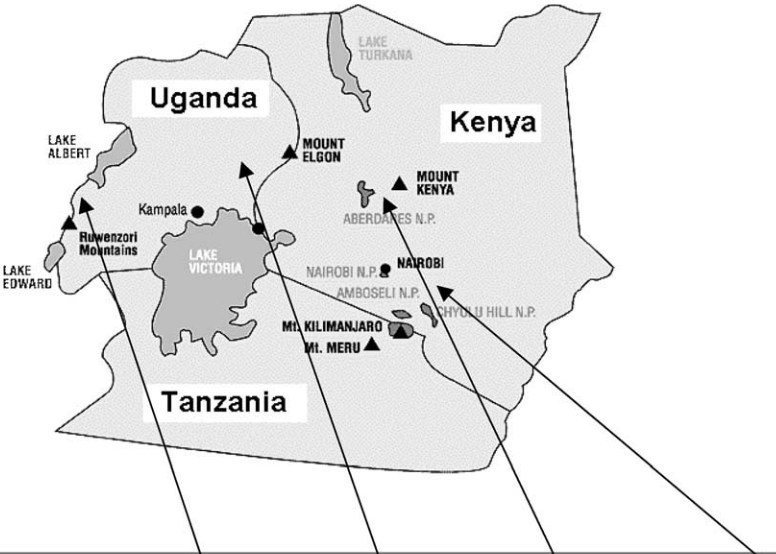
2.1. General approach

The project was implemented in four research sites in Kenya and Uganda (Fig. 1), two with a high agricultural potential (fertile soils, high and reliable rainfall) and two with a medium to low agricultural potential (low soil fertility, low and unreliable rainfall). The nutrient monitoring approach (NUTMON) has been implemented as described in detail by De Jager et al. (1998a, 2001). The approach distinguishes a diagnostic phase where the current soil fertility status, farm management and its influence on resource flows, economic performance and socio-economic environment is assessed. A variety of tools are used such as Participatory Rural Appraisal (PRA), natural resource flow mapping, transect walks and matrix rankings, and a specifically developed quantitative monitoring tool to assess nutrient flows and economic performance indicators. The diagnostic phase is followed by an iterative and participatory technology and policy development phase to address problems identified during the diagnostic phase. During this phase technologies are tested using existing Participatory Technology Development (PTD) methods (Reijntjes et al., 1992) and policy options are explored during a series of workshops with policymakers.

In this project two farm management groups were distinguished and compared:

- 'LEIA management' defined as farm households trained in low-external input technologies (composting, application of liquid manure etc.) and having applied at least three of these techniques on more than 50% of the cultivated area over a minimum of 3 consecutive years.
- 'Conventional management' defined as farm households with similar production resources as the LEIA management group not practising any of the defined LEIA techniques and being representative of the common farming systems characteristics in the catchment.

The differences between the management systems were quantified at the start and monitored during the implementation of the project (Table 1).



	Kenya		Uganda	
District	**Kabarole**	**Pallisa**	**Nyeri**	**Machakos**
Agric. Potential	High	Medium-low	High	Medium-low
Altitude (m.a.s.l.)	1500-1800	1000-1100	1100-2400	500-1300
Rainfall (mm)	1300-1500	800-1200	1200-2000	500-900
Soils (main type)	Andepts	Ferrasols	Andodols, Nitisols (clay)	Luvisols (loamy-sand)
Av. Slope (%)	20	1	21	17
Pop. dens. (n/km2)	400	220	250	100
Av. Land size (ha)	1.6	2.6	0.9	2.5
Crops	Banana, Tea, Maize, Coffee	Maize, cotton, beans Cattle (free-range)	Tea, coffee, maize	Maize, beans, sorghum
Livestock	Cattle (zero-grazing)		Dairy cattle (zero-grazing)	Cattle (corralled at night)

Fig. 1. Research sites and characteristics.

2.2. *Farm selection*

A representative catchment within each administrative district was selected, after which 14–18 farm households per district were included in the research, divided over two management groups according to the criteria set for LEIA and conventional management. The actual selection process commenced with a workshop for the whole community aiming at discussing the objectives, creating ownership of the project and discussing criteria for participation. LEIA farm households were selected by the community in close co-operation with the NGO-staff. The latter ensured that the formulated selection criteria (representativeness for the catchment, definition of LEIA) were met. The matching group of farms with conventional farm management was selected in a similar process, whereby the NGO-staff assessed the

Table 1
Application levels of LEIA farming techniques of farms with conventional and LEIA farm management in Machakos district, Kenya[a]

Soil fertility management practice	% Farm households applying			
	Conventional		LEIA	
	Year 1	Year 2	Year 1	Year 2
Short-term practices				
Composting	10	100	100	100
Intercropping	90	90	88	88
Crop rotation	80	80	100	100
Double digging	0	20	75	75
Deep digging	0	30	50	50
Natural pesticides	0	20	75	75
Tree nurseries	10	10	63	63
Liquid manure	0	0	63	63
Long-term practices				
Fanya yuu (terracing)	100	100	–	–
Cut-off drains	42	42	37	37

[a] 'Year' refers to year of project implementation.

similarity of production resources with the LEIA group (land, animals, soil type, access to water, etc.). All farms were finally included only after a farm visit by the NGO-staff and further discussions with the farm household members verifying the selection criteria and motivation for participation.

2.3. Participative diagnosis of soil fertility status and management practices

The diagnosis consisted of the following activities: (1) farm households' assessment of natural resources, (2) soil sampling, (3) monthly monitoring, (4) analysis. Farm households' perceptions of the current soil fertility management practices were identified through methods such as farmers' soil maps, transect walks (Reijntjes et al., 1992), nutrient flow maps and group discussions. Based upon the farmer' soil maps, a soil analysis was conducted for N, P, K and organic matter content. Monthly monitoring of the farm management practices was done using structured questionnaires and sampling of nutrient contents of major input and output flows conducted. In order to calculate nutrient flows and balances, additional data were collected to feed the transfer functions, simple models and the background database (Vlaming et al., 2001). At farm household level economic performance indicators such as net farm income, household net cash flow and returns to labour were calculated, while at activity level gross margins and net cash flows for crop and livestock were determined. In addition, a simple environmental analysis was made in which the costs of replacing the lost nutrients were valued at farm-gate fertilizer prices (De Jager et al., 1998b). Analysis of the data consisted of (1) farmers' assessment of natural resource management and economic performance, (2) the quantitative nutrient flows and economic performance using the NUTMON methodology and soil sample results, (3) integration of the two previous steps and discussing results with participating farmers.

2.4. Identification, testing and evaluation of low-external-input technologies

Impact assessment of selected LEIA techniques on the two management groups was done over two seasons through a PTD process (Reijntjes et al., 1992) including the following steps: problem identification, identification of technical options for experimentation, inventory of farmers criteria and indicators for evaluating LEIA technologies, and implementation and evaluation of on-farm trials. A training of the project staff was conducted to facilitate the implementation of the PTD process. The skills gained from the training were used to conduct 'experimentation design workshops' in four research sites, followed by implementation of PTD activities. The workshops commenced with a rehearsal of the results of the problem diagnosis, after which researchers and farmers presented separately potential technologies to address the observed problems. Using various group dynamic tools such as sub-group discussion, visual tools and brainstorm sessions one or more technologies were selected for testing, treatments were designed, data collection procedures agreed upon and action plans drawn for implementation of activities. Simple record sheets were designed for data collection by farmers in addition to quantitative data collected by the research staff. Results were evaluated at three levels: individual farmer's evaluation, joint evaluation among farmers during field days and joint evaluation during group meeting involving farmers, extension staff and researchers.

2.5. Formulation of enabling policies and measures at district level

Based upon the participative diagnosis, the results of the on-farm testing programme, an inventory of historic developments in the district, and an inventory of the existing and relevant policies in the research sites, draft qualitative scenarios for future developments in the areas were formulated. The scenarios described three possible development paths for soil fertility management in the coming 15 years on the basis of identified key indicators: net farm income, productivity of the farming system, nutrient flows and balances, food security. In district workshops in each research area, all relevant stakeholders (Ministry of Agriculture and Rural Development, Ministry of Environment and Natural Resources, provincial administration, development agencies and NGOs, research institutions, extension office and staff, input suppliers, farmers and farmers' representatives, media reporters) discussed these scenarios. Thereafter a vision for a desired situation within 15 years was formulated, the conditions necessary to arrive at this desired situation, the most constraints likely to be encountered and actions necessary by various actors to overcome these constraints.

3. Results

3.1. Diagnosis of soil fertility status and management practices

For all farms, farm soil maps, soil maps analysis and nutrient flow maps were produced jointly by farmers and project staff (Fig. 2). These maps enabled farmers to visualise the nutrient flows on their farms, provided insight in farmers' perceptions of soil nutrient status and flows and contributed, together with the quantitative analysis, to the overall problem analysis of soil nutrient depletion status. Application of the NUTMON model resulted in a quantitative assessment of the soil nutrient status, flows and economic performance indicators of the current farming systems. Only marginal differences were observed between the conventional and LEIA farm management systems (Table 2). The differences between the districts were much more profound. The high potential areas, although different in farming system, both showed a relative high N, P, K nutrient content of the soil, but also more negative nutrient balances at farm level, especially for N (90–125 kg ha^{-1} $year^{-1}$ representing an annual 0.7–1.8% loss of the stock). The latter was mainly due to high erosion, leaching and gaseous losses, and despite relative high uses of mineral and organic fertilizers (Table 3). In the low potential areas the differences in

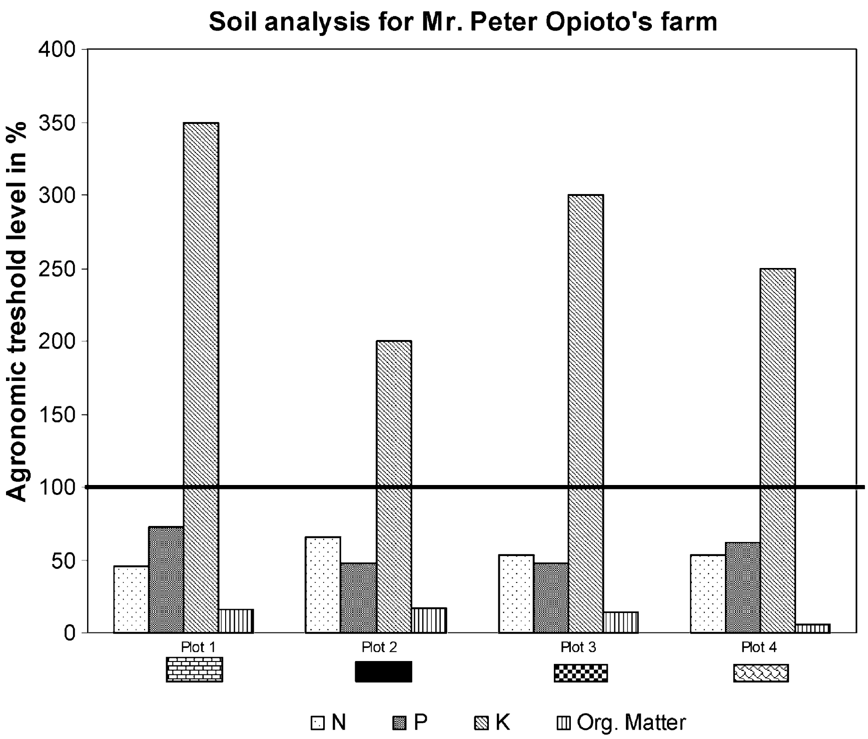


Fig. 2. Example of soil sample feedback report in Palissa district, Uganda.

Table 2
Nutrient stocks and flows in four districts in Kenya and Uganda in the period 1997–1998 (average of 2 years)[a]

	Machakos (LPA)		Nyeri (HPA)		Pallisa (LPA)		Kabarole (HPA)	
	CONV	LEIA	CONV	LEIA	CONV	LEIA	CONV	LEIA
N-stock (kg/ha)	3900	6400	12,200	12,300	3100	3000	6800	8300
N-flow (kg ha^{-1} year^{-1})	−21	−25	−99	−91	−3	−4	−126	−95
N-flow (% of stock year^{-1})	−0.5	−0.4	−0.8	−0.7	−0.1	−0.1	−1.8	−1.1
P-stock (kg/ha)	2000	1700	7900	8000	1000	2500	10,300	9000
P-flow (kg ha^{-1} year^{-1})	2	1	−23	−27	0	0	−70	−57
P-flow (% of stock year^{-1})	0.1	0.1	−0.3	−0.3	0	0	−0.7	−0.6
K-stock (kg/ha)	7800	10,200	10,400	15,300	6100	6300	7800	8400
K-flow (kg ha^{-1} year^{-1})	−9	2	−23	18	2	1	−55	−7
K-flow (% of stock year^{-1})	−0.1	0	−0.2	0.1	0	0	−0.7	−0.1

[a] LPA, low-medium potential area; HPA, high potential area; CONV, conventional farm management practices; LEIA, low-external-input farm management practices; and N, P, K stock measured as N—total, P—total and K—total.

Table 3
Average farm level nitrogen flows per type, research site and management type in Kenya and Uganda in the period 1997–1998 (in kg ha^{-1} year^{-1}; average of 2 years)

	Machakos (LPA)		Nyeri (HPA)		Pallisa (LPA)		Kabarole (HPA)	
	CONV	LEIA	CONV	LEIA	CONV	LEIA	CONV	LEIA
Mineral fertilizer	5	2	64	68	0	1	0	0
Organic inputs	5	9	32	74	5	7	20	17
Atmospheric deposition	4	4	6	6	4	4	5	5
Biological fixation	8	10	7	7	1	1	15	12
Crop/livestock products	−2	−2	−38	−30	−1	−2	−3	−3
Crop residues	−2	−5	−8	−6	−2	−2	−9	−7
Leaching	−20	−26	−56	−58	−7	−7	−65	−76
Gaseous losses	−7	−10	−44	−48	0	−1	−18	−21
Erosion	−8	−5	−54	−95	0	0	−66	−18
Human excreta	−4	−2	−8	−9	−3	−5	−5	−4
Total	−21	−25	−99	−91	−3	−4	−126	−95

farming system were clearly reflected in the soil nutrient flows. In Machakos district (Kenya), intensive crop farming on relative poor soils results in negative nutrient balances for N and K of −21 and −9 kg ha^{-1} year^{-1}, respectively, mainly due to very low levels of external inputs applied. The low potential area in Pallisa district (Uganda) is characterised by a much more extensive farming system with relatively large numbers of free-ranging livestock. The prominence of free-range livestock in the subsistence oriented farming system concentrates nutrients from the communal lands through grazing into the areas for crop cultivation. At farm level this results into a nearly balanced situation of nutrient flows. However, this situation can only remain stable as long as sufficient common grazing land in the district remains available.

The economic performance indicators showed no clear differences between the LEIA and conventional management systems (Fig. 3). However, analysis of labour data showed that LEIA management required more labour than conventional management. The farms in high potential areas realised higher net farm income both per farm and per unit area. In Kenya off-farm income is of crucial importance to the total family income, reducing the differences in financial resources between the Machakos and Nyeri districts. Huge differences between districts were observed in the replacement cost of nutrients, a method in which the depleted nutrients are considered to have an economic value equal to the market value (at farm gate prices) of an equivalent amount of fertilizers. In Pallisa the replacement cost made up only 5% of the net farm income while in Nyeri these costs were also relatively low (11%). In Machakos and Kabarole a considerable proportion of the net farm income was based upon nutrient mining with respective figures of 25–30% and 60–70%. The economic efficiency of crop activities, expressed in gross margins per hectare, tended to be slightly higher for the LEIA farm management systems. Extrapolating poverty line studies by the World Bank in 1992, the poverty line of an average farm household in Kenya consisting of 5 adult equivalent units was estimated at US$ 1300 per year. In the studied districts the average income from farming alone was far below

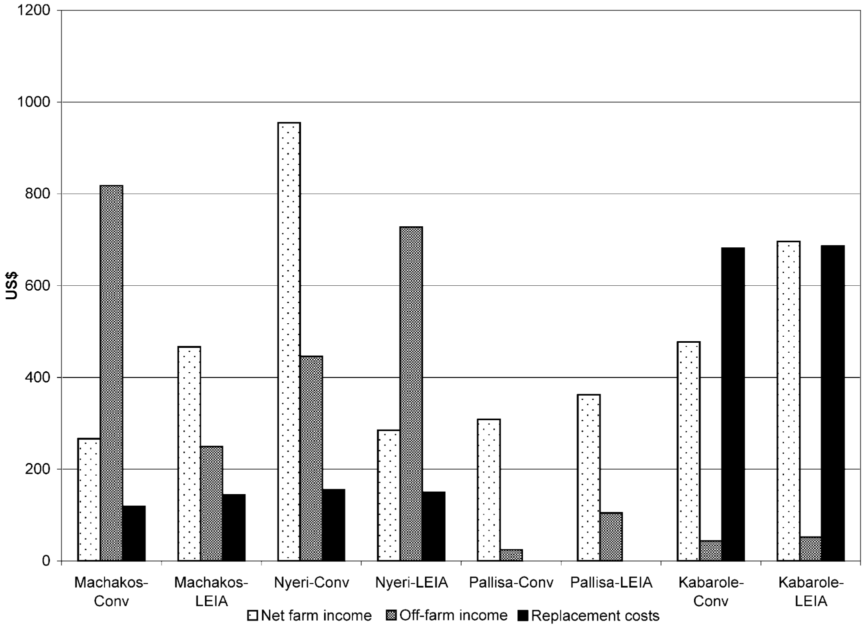


Fig. 3. Average net farm income, off-farm income and nutrient replacement costs per farm per year in four research sites and for two management types in Kenya and Uganda in the period 1997–1998 (average of 2 years). Conv, conventional farm management practices; LEIA, Low-external-input farm practices.

that line (Machakos US$ 390, Nyeri US$ 1050). Only in the high potential area of Nyeri the combined average farm and off-farm income was above this poverty line.

3.2. Identification, testing and evaluation of low-external input technologies

The results of the analysis of nutrient balances in the area were shared during meetings with farmers. Visual aids were used as discussion points, and to explore the possible options for preventing further decline in soil fertility (Table 4). Possible constraints to using the proposed technologies are lack of materials for making compost, shortage of labour for building terraces along contours, and lack of cash for purchasing inputs. Finally, the experiments selected by the group focused on recycling nutrients through composting and liquid manure, while no nutrient adding and hardly any nutrient saving techniques were selected. In general, the results showed that significant increases in yield and economic returns can be realised with relatively high application levels of compost, but that availability of material and labour inputs soon became limiting factors (Table 5). No obvious differences in impact of the tested LEIA techniques between LEIA and Conventional management groups were observed. Follow-up experimentation by farmers give the impression that substantial yield increases with reasonable economic returns can only be realised through combinations of fertilizers and locally available organic resources (Table 6). But for all tested technologies relatively low value–cost–ratio's were found. Apart from yield and economic returns, farmers' assessed the technologies also on aspects such as impact on soil structure, incidence of weeds, moisture retention, leaf colour, seed quality, cash saving or generating and incidence of pest and diseases. Through matrix ranking, scores to each of these indicators were given, compared to the quantitative results and discussed in group meetings.

The PTD process increased farmers' capacity to experiment, and improved their confidence in their own ability to find solutions to different problems. At the end of trial period they were experimenting independently, trying out *tithornia* as a green

Table 4
Suggestions by farmers for improvements in soil fertility management

LEIA farmers	Conventional farmers
• Increasing the quantity of manure and compost	• Covering manure or compost to reduce gaseous losses
• Using additives to improve the quality of compost	• Using additives when preparing compost
• Avoiding the use of compost or manure that is not fully decomposed	• Incorporating crop residues into the soil
• Incorporating compost into the soil as soon as possible to minimize gaseous losses	• Planting leguminous plants, e.g. cowpea
• Covering compost heaps	• Applying liquid manure
• Installing more soil and water conservation structures.	• Applying the correct dose of fertilizer
• Planting leguminous crops	• Rotating crops
	• Taking measures to reduce soil erosion

Table 5
Results of low-external inputs selected, tested and evaluated in four research sites in Kenya and Uganda in the period 1997–1998

Research site, management type and test crop	Technologies tested	Yield (kg/ha)		Gross margin (US$/ha)	
		Year 1	Year 2	Year 1	Year 2
Machakos, conventional, maize	Farmers' practices (17 t/ha manure and 140 kg/ha DAP[a])	2400	–	325	–
	Compost (32 t/ha)	3225	–	400	–
	Compost (32 t/ha) and liquid manure (7 t/ha)	3970	–	443	–
	Farmers' practices adjusted (8.5 t/ha and 140 kg/ha DAP[a])	–	1275	–	207
	Compost (16 t/ha)	–	1575	–	182
	Compost (16 t/ha) and liquid manure 7 t/ha)	–	1700	–	168
Machakos, LEIA, maize	Farmers' practices (17 t/ha compost)	2225	–	325	–
	Compost (32 t/ha)	3225	–	404	–
	Compost (32 t/ha) and liquid manure (7 t/ha)	4325	–	511	–
	Farmers' practices adjusted (8.5 t/ha)	–	1450	–	279
	Compost (16 t/ha)	–	1400	–	250
	Compost (16 t/ha) and liquid manure (7 t/ha)	–	1975	–	296
Nyeri, conventional, cabbage	Farmers practices (42 t/ha manure and 600 kg/ha DAP[a])	30,000	–	857	–
	Compost (42 t/ha)	40,000	–	929	–
	Residual impact of farmers' practices	–	5000	–	–36
	Residual impact of compost application the year before	–	10,000	–	36
	Farmers' practices adj. (21 t/ha manure and 600 kg/ha DAP[a])	–	22,500	–	1143
	Compost adjusted (21 t/ha)	–	15,000	–	643

(continued)

Table 5 (*continued*)

Research site, management type and test crop	Technologies tested	Yield (kg/ha)		Gross margin (US$/ha)	
		Year 1	Year 2	Year 1	Year 2
Nyeri, LEIA, cabbage	Farmers practices (42 t/ha compost)	40,000	–	929	–
	Compost (42 t/ha) and liquid manure (17 t/ha)	42,500	–	929	–
	Residual impact of farmers' practices	–	5000	–	0
	Residual impact of compost and liquid manure application	–	5000	–	0
	Farmers' practices adjusted (21 t/ha compost)	–	12,500	–	464
	Compost (21 t/ha and liquid manure (12.5 t/ha)	–	22,500	–	1071
Pallisa, convenional, maize (Year 1) and groundnuts (Year 2)	Control	1150	–	156	–
	Deep tillage	1600	–	172	–
	Compost (32 t/ha)	1700	–	−188	–
	Deep tillage + compost (32 t/ha)	2125	–	−156	–
	Control (residual impact next year)	–	1225	–	875
	Deep tillage (residual impact next year)	–	1275	–	922
	Compost (32 t/ha) (residual impact next year)	–	1525	–	1125
	Deep tillage + compost (32 t/ha) (residual impact next year)	–	1700	–	1281
Pallisa, LEIA, maize (Year 1) and groundnuts (Year 2)	Control	1375	–	188	–
	Mulch application	1875	–	250	–
	Compost (32 t/ha)	2775	–	−31	–
	Compost (32 t/ha) + Mulch	2450	–	−109	–
	Control (residual impact next year)	–	1050	–	734
	Mulch application (residual impact next year)	–	1375	–	984
	Compost (32 t/ha) (residual impact next year)	–	1025	–	734
	Compost (32 t/ha) + mulch (residual impact next year)	–	1350	–	969

(continued)

Table 5 (*continued*)

Research site, management type and test crop	Technologies tested	Yield (kg/ha)		Gross margin (US$/ha)	
		Year 1	Year 2	Year 1	Year 2
Kabarole, conventioanl, maize (Year 1) and Beans (Year 2)	Control	5425	–	859	–
	Manure (150 t/ha)	7625	–	47	–
	Control (residual impact next year)	–	1975	–	500
	Manure (150 t/ha) (residual impact next year)	–	2725	–	688
Kabarole, LEIA, maize (Year 1) and beans (Year 2)	Control	5225	–	938	–
	Manure (150 t/ha)	5850	–	438	–
	Control (residual impact next year)	–	1425	–	359
	Manure (150 t/ha) (residual impact next year)	–	1825	–	453

[a] DAP, diammonium phosphate.

Table 6
Results of farmers' experiments with organic and inorganic input combinations on maize in Machakos District, Kenya in 1999 (averages of two cropping seasons)

	Irrigated		Non-irrigated	
	Yield (kg/ha)	VCR[a]	Yield (kg/ha)	VCR
Farmers' practice	2416 (1857)[d]	–	813 (741)	–
5 t /ha FYM	1978 (1855)	−1.75	613 (606)	−0.80
130 kg/ha DAP[b] + 135 kg/ha CAN[c]	2988 (1674)	0.87	1263 (1024)	0.31
5 t /ha FYM + 135 kg/ha CAN	2634 (1674)	0.40	943 (756)	0.24
5 t /ha FYM + 130 kg/ha DAP + 135 kg/ha CAN	3500 (1999)	1.19	1475 (1038)	0.73

[a] VCR, value cost ratio.
[b] Standard deviation between parentheses.
[c] DAP, diammonium phosphate.
[d] CAN, calcium ammonium nitrate.

manure, testing different doses of compost on various crops, conducting trials with plant density and spacing, and adapting techniques tried out during the PTD phase. Farmers were exposed to a whole range of new soil fertility management options through their dialogue with researchers and extension agents, and many have changed their management practices since participating in the research process. Crop residues were better managed, as they were incorporated into the soil soon after harvest, and as farmers became more aware about soil and water conservation practices in general, they were quicker to repair broken terraces and stabilise terrace embankments. Manure and compost were recognised as important soil amendments, and all 18 participating farmers were producing more compost and used various additives to improve its quality, such as *Tithornia* sp. and wood ash. Manure and compost heaps were no longer left in the open for long periods, but were now shaded with various locally available materials, and only taken to the field just before being incorporated into the soil. As they cannot produce enough compost and manure to fertilise whole fields over a single cropping season, farmers applied these inputs on a rotational basis. They have started using mulches in their kitchen gardens and planted agro-forestry tree species, such as *Sesbania* sp., in scattered stands in fields or along hedges.

A year after the active phase of the study ended, participating farmers continued to meet regularly, sharing their knowledge, experiences and resources, and taking turns working on each other's farms to compensate for labour shortages. They also started contributing financially to local projects, demonstrating that the approach has succeeded in strengthening existing local institutions and establishing horizontal links between various groups. With greater interaction between farmers and extension, visits of the latter to the research site have continued even though the programme has finished. The research process has helped bridge the gap between extension services and farmers and the agency now uses the 'research groups' as its point of contact with farmers.

3.3. Formulation of enabling policies and measures at district level

The four workshops attended by in total 150 stakeholders, gave stakeholders further insights into nutrient balances and soil fertility management in general, which ended with the elaboration of an action plan for overcoming various constraints (Table 7). During the course of the workshops, it became clear to the participants that while community initiatives are a fundamental requirement for change, better targeting and timely implementation of agricultural policies are also needed to facilitate the processes of change. Policies should be designed to encourage farmers to invest in soil fertility. Central government, however, is still seen as the dominant force shaping policies, largely excluding community and civil society groups from the policy process. Most participants agreed that policies are mostly formulated and implemented in a 'top-down' process, and that extension agents and researchers have little opportunity to express their concerns at district or national level. As a result of the workshops in Kenya one local Member of Parliament raised a question on soil fertility related policies in the national parliament, while in Uganda the chairman of the Kabale district council proposed that the proceedings of the workshop should be written in simpler language enabling him to develop proposals for by-laws to improve management of soils in the district.

4. Discussion and conclusions

The participatory approach used in this research demonstrated the potential synergy and complementarity of the knowledge held by farmers, extension agents and researchers. Working through an inclusive process of dialogue, observation, diagnosis, experimentation and exposure to different types of knowledge, participants made a thorough analysis of the current soil fertility situation and tested various LEIA options for improving soil fertility management.

In all four research sites and all studied soil nutrient management systems the future agricultural productivity is seriously threatened by soil nutrient depletion. The cause of depletion however differs considerably between the sites. Soil nutrient analysis revealed that no differences in soil nutrient status could be observed between LEIA and conventional management. Apparently, application of low-external input techniques such as compost, liquid manure etc. did not result in a significantly better soil fertility status (measured in N, P, K and C content) compared to conventional practices such as application of farm yard manure, fertilizers, etc. In general, the nutrient status was considerably higher in the high potential areas compared to the low potential areas. Overall soils were adequately supplied with potassium and deficient in phosphorous. Large variations were observed in soil fertility management, soil nutrient flows, nutrient balances and economic performance indicators between farms within one management group in a particular research area.

In general, rather low and erratic economic returns to agricultural production activities were observed, and moreover a considerable part of these returns are based

Table 7
Summarised results from district stakeholders workshop in Machakos

	Scenarios		
Key indicator	Business-as-usual	Low-input subsistence	INM-commercial
Agricultural production	• Gradual declining crop yields due to reduced manure input/availability • Reduced livestock production at farm level	• Stable yield levels	• Increasing yields; commercial crops • Increased output from livestock; especially milk
Economic performance	• Declining gross margins for crop and livestock	• Remaining relatively low levels of economic return • Increased importance of off-farm income	• Increased gross margins • High capital costs • Agricultural related off-farm income • Soil fertility
	• Negative nutrient balances at farm and plot level and gradually declining soil fertility	• Slightly negative nutrient balances due to limited external inputs	• Higher in and out flows • Soil fertility maintained
Food security	• Food insecure; out migration	• Improved food security; vulnerable to climatic fluctuations	• Food secure for large group of people • Increased gap between rich and poor

Action plan

Soil fertility management

- Use locally available resources to improve soil organic matter content
- Step up water harvesting techniques
- Conduct more training to raise awareness of the range of soil fertility management techniques
- Increase research into alternative technologies

Access to inputs

- Promote co-operative management strategies to enable farmers to pool their resources
- Reduce dependency on government subsidies by promoting the use of local resources

Improving rural development

- Provide artificial insemination services at village level
- Use local processing to add value to farm products
- Mobilise the community to take action on various agricultural development issues
- Facilitate the acquisition of title deeds to encourage investment in short- and long-term soil fertility management strategies
- Credit provision
- Facilitate marketing to improve output–input price ratios
- Improve rural infrastructure

upon nutrient mining. LEIA farm management resulted in similar net farm income levels as conventional farm management. In the low potential areas slightly higher income levels were realised with LEIA management. But in general the current socio-economic environment is not conducive for farmers to undertake short- and long-term investment in soil fertility and soil nutrient management. Off-farm income is an increasingly important factor in family income, especially in Kenya. Therefore a targeted exploration of value-added production alternatives is required to sustain livelihoods in rural areas. Research and development initiatives addressing soil fertility depletion in relation to sustainable livelihood improvement in East Africa should widen its focus beyond the agricultural sector.

Low-external-input technologies alone offered limited opportunities to address the observed problems of soil nutrient depletion in the region. Significant increases in yield and economic returns could be realised with relatively high application levels of compost, but availability of material and labour inputs then become limiting factors. On the other hand, an increased application of external inputs alone is also not a realistic solution. For the vast majority of smallholders this option is economically not feasible, the required infrastructure is lacking and may lead to high losses in nutrients in areas sensitive to leaching and erosion. Appropriate combinations of external inputs and LEIA techniques appear the most appropriate alternative strategy: maximal use of local available nutrients combined with an (environmental–economic) optimal use of external nutrients. More emphasis should be paid to reduction of nutrient losses when using locally available organic resources. Caution in general interpretation of the experimental results is necessary since only results of two seasons were evaluated on a limited number of plots, while some impacts of changes in soil fertility management can manifest themselves only after a number of years.

At farm level, the research process helped establish new and sustainable partnerships between extension agents, researchers and farmers. It raised farmers awareness of declining soil fertility, encouraging them to adopt and adapt new methods of addressing the problem. Farmers' willingness to change their practices, as shown in the changing management practices of the conventional management group, revealed a flexibility and ability to tailor management strategies to changing circumstances and experiences, in contrast to the received wisdom that they simply tend to follow tradition.

Institutional aspects need to be addressed in a more structured way. A smooth long-term collaboration between research institutions and universities on the one hand and extension staff and NGO's on the other is a prerequisite for a successful and sustainable implementation of the approach. In future activities, a structured plan of collaboration needs to be developed beyond the time horizon of projects or activities.

Effective communication between stakeholders is needed to facilitate positive changes in soil fertility management at all levels, which will also require their involvement in a range of decision making processes, from selecting test technologies to targeting capacity building initiatives, improving the infrastructure and designing and implementing policies. In particular the results of the nutrient balance studies have been used to inform policy makers and raise awareness on declining soil fertility. However, it was not possible to initiate effective policy processes within the project time frame, as policy makers were not involved at a sufficiently early stage of the programme. While for participation processes at farm household level a wide array of methods and experiences have been documented (Loevinsohn et al., 2002; Hagemann and Chuma, 2002; Defoer, 2000), relatively limited successful experiences have been gathered on communication tools and participation processes to enable an effective interaction between policy makers and researchers. This is still a major constraint in many research projects and requires urgent attention.

Acknowledgements

The European Union and the Dutch Ministry of Agriculture, Nature Management and Fisheries are gratefully acknowledged for supporting this research. The authors thank the anonymous reviewers for their constructive comments.

References

Blaikie, P., Brown, K., Stocking, M., Tang, L., Dixon, P., Sillitoe, P., 1997. Knowledge in action: local knowledge as a development resource and barriers to its incorporation in natural resource research and development. Agricultural Systems 55 (2), 217–237.

Braun, A.R., Smaling, E.M.A., Muchugu, E.I., Shepherd, K.D., Corbett, J.D., 1997. Maintenance and Improvement of Soil Productivity in the Highlands of Ethiopia, Kenya, Madagascar and Uganda; An Inventory of Spatial and Non-spatial Survey and Research Data on Natural Resources and Land Productivity (African Highland Initiative Technical Report Series No. 6). ICRAF, Nairobi, Kenya.

Defoer, T., Budelman, A., Toulmin, C., Carter, S.E., 2000. Building common knowledge. Participatory learning and action research (part 1). In: Defoer, T., Budelman, A. (Eds.), Managing Soil Fertility in the Tropics. A Resource Guide for Participatory Learning and Action Research. KIT, Amsterdam.

De Jager, A., Onduru, D., Van Wijk, M.S., Vlaming, J., Gachini, G.N., 2001. Assessing sustainability of low-external-input farm management systems with the nutrient monitoring approach: a case study in Kenya. Agricultural Systems 69, 99–118.

De Jager, A., Nandwa, S.M., Okoth, P.F., 1998a. Monitoring nutrient flows and economic performance in African farming systems (NUTMON). I. Concepts and methods. Agric. Ecosyst. Environ. 71 (1–3), 37–48.

De Jager, A., Kariuki, F.M., Matiri, M., Odendo, Wanyama, J.M., 1998b. Monitoring nutrient flows and economic performance in African farming systems (NUTMON). IV. Monitoring of farm economic performance in three districts in Kenya. Agric. Ecosyst. Environ. 71 (1–3), 81–92.

Hagmann, M.E., Chuma, E., 2002. Enhancing the adaptive capacity of the resource users in natural resource management. Agricultural Systems 73, 23–39.

Koning, N., Heerink, N., Kauffman, S., 1998. Integrated soil improvement and agricultural development in West Africa: why current policy approaches fail. Wageningen Economic Papers 9–98.

Loevinsohn, M.E., Berdegue, J.A., Guijt, J., 2002. Deepening the basis of rural resource management: learning processes and decision support. Agricultural Systems 73, 3–22.

McCulloch, A.K., Babu, S., Hazell, P., 1999. Strategies for poverty alleviation and sustainable resource management in the fragile lands of sub-saharan Africa. In: Proceedings of the International Conference 25–29 May 1998, Entebbe, Uganda. DSE, Feldafing.

Mokwunye, A.U., De Jager, A., Smaling, E.M.A., 1996. Restoring and maintaining the productivity of West African soils: key to sustainable development. IFDC Miscellaneous Studies No. 9, Lome, Togo.

Pinstrup-Andersen, P., 2000. Food policy research for developing countries: emerging issues and unfinished business. Food Policy 20, 125–141.
Pretty, J.N., 1995. Regenerating Agriculture; Policies and Practice for Sustainability and Self-reliance. Earthscan, London, UK.
Reij, C., Scoones, I., Toulmin, C., 1996. Sustaining the Soil; Indigenous Soil and Water Conservation in Africa. Earthscan, London, UK.
Reij, C., Waters Bayer, A. (Eds.), 2002. Farmer Innovation in Africa: A Source of Inspiration for Agricultural Development. Earthscan, London, UK.
Reijntjes, C., Haverkort, B., Waters-Bayer, A., 1992. Farming for the Future. An Introduction to Low-external-input and Sustainable Agriculture. ILEIA, Leusden, The Netherlands.
Scoones, I., 2001. Dynamics and Diversity: Soil Fertility and Farming Livelihoods in Africa: Case Studies from Ethiopia, Mali and Zimbabwe. Earthscan, London, UK.
Scherr, S.J., 1999. Soil degradation; a threat to developing country food security by 2020? (IFPRI Discussion paper 27). Washington, DC, USA.
Smaling, E.M.A., Braun, A.R., 1996. Soil fertiltiy research in Sub-Saharan Africa: new dimensions, new challenges. Commun. Soil Sci. Plant Anal. 27 (3 and 4), 365–386.
Smaling, E.M.A., Fresco, L.O., De Jager, A., 1996. Classifying and monitoring soil nutrient stocks and flows in African agriculture. Ambio 25, 492–496.
Smaling, E.M.A., Oenema, O., Fresco, L.O., 1999. Nutrient Disequilibria in Agroecosystems. CABI, Cambridge, UK.
Smaling, E.M.A., Stoorvogel, J.J., De Jager, A., 2002. Decision making on Integrated Nutrient Management through the eyes of the scientist, the land-user and the policy maker. In: Vanlauwe, B., Diels, J., Sanginga, N., Merckx, R. (Eds.), Integrated Plant Nutrient Management in Sub-Saharan Africa. CABI, Wallingford, UK.
Stoorvogel, J.J., Smaling, E.M.A., Janssen, B.H., 1993. Calculating soil nutrient balances at different scale. I. Supra-national scale. Fert. Res. 35, 227–235.
Van der Pol, F., 1993. Analysis and evaluation of options for sustainable agriculture, with special reference to southern Mali. In: van Reuler, H., Prins, W.H. (Eds.), The Role of Plant Nutrients for Sustainable Food Crop Production in Sub Saharan Africa. VKP, Leidschendam.
Van Reuler, H., Prins, W.H. (Eds.), 1993. The Role of Plant Nutrients for Sustainable Food Crop Production in Sub-Saharan Africa. VKP, Leidschendam.
Vlaming, J., Van den Bosch, H., Van Wijk, M.S., De Jager, A., Bannink, A., Van Keulen, H., 2001. Monitoring Nutrient Flows and Economic Performance in Tropical Farming Systems; Part 1: Manual for the NUTMON Toolbox. Wageningen University and Research Center, The Netherlands.

Chapter 7 Attaining sustainable farm management systems in semi-arid areas in Kenya: few technical options, many policy challenges

De Jager, A., van Keulen, H., Mainah, F., Gachimbi, L.N., Itabari, J.K., Thuranira, E.G., Karuku, A.M., 2005.

Attaining sustainable farm management systems in semi-arid areas in Kenya: few technical options, many policy challenges.

International Journal for Sustainable Agriculture 3 (3): 189-205.

INTERNATIONAL JOURNAL OF AGRICULTURAL SUSTAINABILITY Vol. 3, No. 3, 2005
1473-5903/05/03 0189-17 $20.00/0
© 2005 A. De Jager *et al.*

Attaining Sustainable Farm Management Systems in Semi-Arid Areas in Kenya: Few Technical Options, Many Policy Challenges

A. De Jager[1], H. van Keulen[2,5], F. Mainah[3], L.N. Gachimbi[3], J.K. Itabari[4], E.G. Thuranira[3] and A.M. Karuku[4]

[1]Wageningen University and Research Centre – Agricultural Economics Research Institute (LEI), Den Haag, The Netherlands; [2]Wageningen University and Research Centre – Plant Research International, Wageningen, The Netherlands; [3]Kenya Agricultural Research Institute (KARI) – National Agricultural Research Laboratories (NARL), Nairobi, Kenya; [4]Kenya Agricultural Research Institute (KARI) – Land and Water Research Management, Machakos, Kenya; and [5]Wageningen University – Group Plant Production Systems, Wageningen, The Netherlands

Soils in arid and semi-arid lands (ASAL) are fragile, low in fertility and susceptible to erosion and leaching. To address these problems, activities were implemented in 1998–2003 to identify current problems, and design, test, implement, demonstrate and disseminate improved, integrated soil fertility management techniques. Current soil fertility management results in slightly negative nutrient balances, especially for phosphorus and potassium. Recycling of nutrients through crop residues and animal manure is inefficient, with evidently high losses. Due to the relatively high price of fertilisers and the high risks of crop failure, use of mineral fertilisers is restricted to market-oriented farms with access to irrigation facilities. Of the total farm household population, 35–85% lives below the poverty line. Applying higher rates of Farm Yard Manure (FYM) and/or fertilisers is unattractive and risky. Combinations of FYM and fertilisers give better financial returns than either of the two alone. Where irrigation is available, farmers adopt innovative farming systems that include higher application of mineral and organic fertilisers, and result in higher and more stable yields and higher financial returns. A set of specific policy measures for the semi-arid areas were identified to arrive at necessary changes in the economic environment, leading to a wider range of financially attractive technology options for smallholders.

Keywords: ecological and economic sustainability, Kenya, natural resource management, rural livelihoods, semi-arid areas

Introduction

Eighty percent of Kenya's land surface is made up of arid and semi-arid lands (ASAL) and the rest being of high agricultural potential and carrying more than 75% of the total population. The rapid increase in Kenya's population, especially over the last 30 years, has resulted in rural–urban migration and out-migration from the high agricultural potential to semi-arid and arid areas in search of new farmlands. The associated introduction of crop production technologies from high potential areas, including continuous cultivation of favourite crops, has proven unsuitable and often results in low yields or complete crop failure, mainly because of unreliable rainfall, both in quantity and distribution (Jaetzold & Schmidt, 1983; Jones & Thornton, 2002; Mantel & van Engelen, 1999). Moreover, the increased pressure on land necessitated intensification of land use, often without the necessary external inputs to sustain its productivity. Since soils in ASAL are fragile and low in fertility, and because of their sandy texture, susceptible to erosion (Stephens & Hess, 1999) and leaching, these developments have led to serious decline in soil fertility status and declining crop yields.

Various studies have identified low soil fertility, low adoption of recommended varieties and low plant populations as the main biophysical factors contributing to low crop yields at farm level in semi-arid areas of Africa in general (Bationo *et al.*, 2003; Hartemink & van Keulen, 2005; Lesschen *et al.*, 2004) and also in Eastern Kenya (Anonymous, 1994; Faught *et al.*, 1984; Ikombo, 1984; Okalebo *et al.*, 1996; Okwach & Simiyu, 1999). It has also been shown that if farmers adopt new crop varieties, they do not implement recommendations on improved soil management technologies (Rukandema, 1984; Tiffen *et al.*, 1994). Consequently, many farmers realise only a fraction of the potential productivity gains from adoption of new crop varieties. Limited cash availability within the farm households, high input and low output prices, poor road networks and insufficient marketing infrastructure are considered the main socio-economic constraints.

There is increasing evidence that in addition to the factors mentioned, lack of participation of farmers in the research process and in the design of improved soil management technologies, is a major limiting factor to adoption of technologies (Babu & Hazell, 1999; Defoer & Budelman, 2000; Martin & Sherington, 1997). In response to these observations, increasing attention has been paid to the development and implementation of methods in which the farming community plays a significant role in design and testing of technological innovations (Ashby, 1990; Debrah & Nederlof, 2002; Haverkort *et al.*, 1991; Johnson *et al.*, 2003; Pretty, 1995; Scoones, 2001; Woomer *et al.*, 2002).

To address the problems in the ASAL, the project 'Assessment and monitoring of nutrient flows and stocks to determine appropriate integrated nutrient management strategies for arid and semi-arid lands in Kenya' was implemented in the period 1998–2003. The objective of the project was to design, test and implement, demonstrate and disseminate improved, integrated soil fertility and water management techniques and formulate improved inorganic fertiliser and organic input recommendations for various land use zones, soil types, farming systems and farm types in ASAL through participatory efforts of scientists with all relevant stakeholders (Gachimbi *et al.*, 2002). The paper describes the approach followed and both methodological and substantive results for six sites in four districts in Kenya.

Methodology

The participatory NUTMON-methodology as described in detail by Vlaming *et al.* (2001) and De Jager *et al.* (2001) was applied. In the study, three major components are distinguished: (1) diagnosis and analysis of existing farming and nutrient management systems, (2) participatory learning and experimentation, and (3) stakeholder workshops. In the first two phases, six farmer groups, comprising 111 farm households in total, participated intensively in the research activities during the period 1999–2002. Based on earlier farming system research activities in the area, six representative clusters were selected to cover the variation within the semi-arid areas in Kenya in terms of agro-ecological characteristics, population density and farming system. Five out of the six clusters are occupied by the Kamba tribe while Maasai occupies the Enkorika cluster in Kajiando district. Within each cluster one representative village was selected and farm households were selected during a participatory village 'baraza' (meeting) in each village (Gachimbi *et al.*, 2005).

The diagnostic phase covering a one-year period per farm/cluster, was implemented in the period 1999–2001 and aimed at analysing current nutrient management, determining the magnitude and major sources of nutrient depletion, analysing financial performance, creating farm household awareness of nutrient management aspects and jointly with the farm households, arriving at a research and development agenda. The diagnosis consisted of the following activities: (1) farm households' assessment of natural resources, (2) soil sampling from identified soil units on all the farms with one sample per unit, (3) monthly monitoring, (4) analysis. Farm households' perceptions of current soil fertility management practices were identified through methods such as farmers' soil maps, transect walks, nutrient flow maps and group discussions. Soil units distinguished on the farmers' soil maps, were sampled and analysed for nitrogen (N), phosphorus (P), potassium (K) and organic matter content. Farm management practices were monitored using structured questionnaires, and major nutrient input and output flows were quantified through sampling and chemical analyses. Field and farm nutrient flows and balances, farm household level financial performance indicators such as net farm income, household net cash flow, returns to labour and gross margins were calculated by the research team using the NUTMON methodology (Vlaming *et al.*, 2001).

Participatory learning and experimentation was implemented in the period 2001–2002, covered on average two cropping seasons and combined various elements of participatory research methodologies, including the following steps:

- Group formation. Farm selection was done during a one-day village meeting (baraza) at each of the study sites, attended by farmers, researchers, extension agents, the assistant chief and village elders. The meeting selected participants for the programme based on criteria such as soil fertility management skills, communication skills, gender, etc.

- Sensitisation of farmers on soil fertility status. Based on the results of the activities in the diagnostic phase, farmers' meetings were organised to synthesise and analyse the information obtained (soil analysis results, nutrient flows and balances, financial results) and prioritise the major problems to be addressed.
- Identification and selection of technology options. In a farmers' meeting, technology options to address the prioritised problems were identified. The research teams adopted various modes of discussion: plenary, subgroups, separate groups for men and women. The researchers also presented potential technology options during the meeting. All options were pooled without any order or priority. In a plenary session, the options were ranked by the farmers through consensus or voting.
- Implementation of on-farm experiments. Jointly with the farmers a research protocol was formulated, comprising a hypothesis, test crop, exact description of treatments, experimental layout, aspects to be monitored and/or measured, division of responsibilities between farmers and researchers. In general, a simple experimental layout was designed with one replicate per farm (with other group members implementing similar experiments serving as replicates), plot sizes around 100 m^2 and at most four treatments per experiment.
- Monitoring and data analysis. Records were kept in accordance with the research protocol. Researchers measured aspects such as nutrient contents of manure, plant density and yield. Farmers monitored a variety of factors such as date of planting, date of manure application, emergence date, plant vigour, colour, weed, pest and disease incidence, prices of inputs and outputs, etc. In many cases, farmers were given record books to monitor their observations. Unfortunately, the field teams conducted no structured recording and analysis of these farmers' observations through techniques such as matrix ranking or scoring (Onduru *et al.*, 2001), as was planned.
- Joint researchers and farmers evaluation. During implementation of the experiments, field days were organised, attended by participating farmers, neighbouring farmers, extension staff and local leaders, enabling farmers to share their results and experiences with the community. In a joint meeting of farmers and researchers the experimental results were discussed and evaluated, using criteria such as crop yields, plot-level partial nutrient balances, nutrient use efficiencies, partial gross margins and value cost ratios.

Two consultative stakeholder workshops were organised in 2002 and 2003 to inform major stakeholders and policy makers on project activities and results, and to formulate recommendations and action plans to address the problems in the ASAL in Kenya.

Site Description

The study area comprised parts of Machakos, Mwingi, Makueni and Kajiado Districts (Figure 1). The region is characterised by low, temporally highly variable rainfall, varying on average from 600 mm to 800 mm annually, bi-modally distributed, resulting in two growing seasons. The region belongs to RAEZ1 as defined by TAC (1993). The soils are variable in depth, depending on parent material and slope, and are generally low in organic matter and deficient in nitrogen and phosphorus, whereas potassium levels are generally adequate except in Makueni. Low infiltration rates and susceptibility to surface sealing make the soils vulnerable to erosion at the beginning of the season when the land is bare. Major characteristics of the clusters are summarised in Table 1.

In all clusters, subsistence rainfed farming systems are predominant, with maize and beans as the major crops. Farm households in general own between 1.5 and 6 ha of land, of which 1.5–3.5 ha is cultivated. In Matuu and Kibwezi, part of the farmers has access to simple small-scale irrigation facilities and cultivates mainly vegetables, such as chillies, tomatoes, onions and eggplant. In the majority of the households, livestock (cattle, sheep, goats) represents an important component of the farming system. The major functions of livestock are (Slingerland *et al.*, 1998) provision of draught power, manure production and capital assets (saving and insurance). The farms in Kajiado district are characterised by large herds of livestock on relatively large areas of owned grazing land and small areas of cultivated

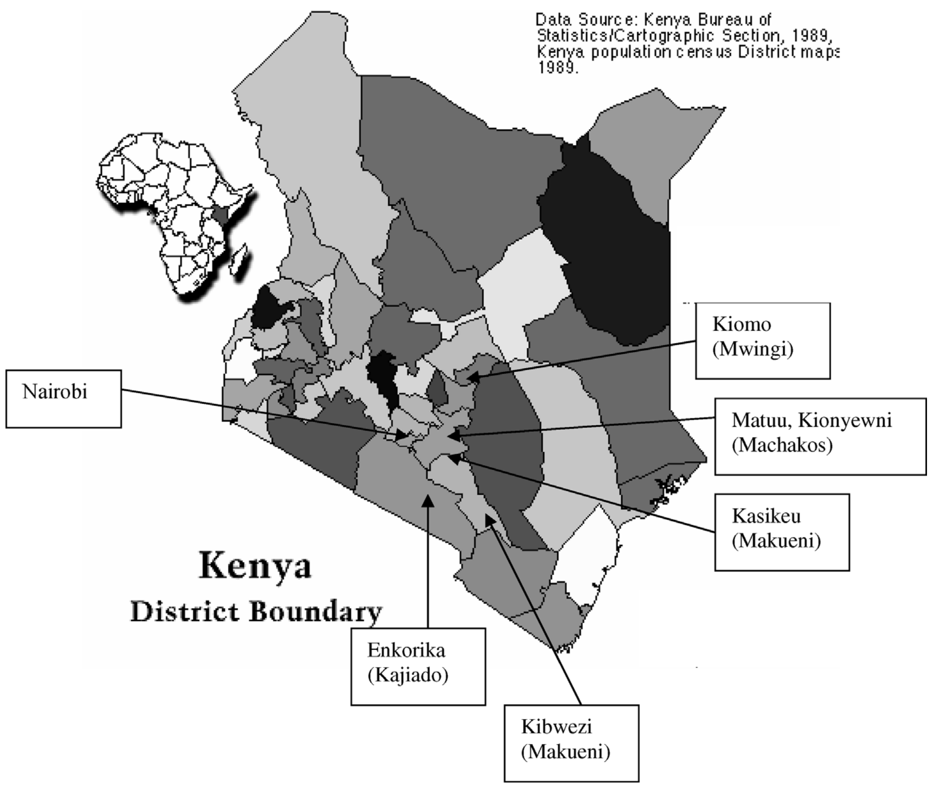


Figure 1 Location of research clusters (the districts between parentheses)

land for subsistence crops. Fallowing has lost its importance in soil fertility management, but land may be left fallow as a result of low rainfall at the start of the season (failed germination).

Results

Diagnostics

Climatic conditions

With the exception of Matuu and Kasikeu clusters, data collected from single meteorological stations in each site, show that rainfall during the monitoring period was much lower than the long-term annual average (Table 2) and was unevenly distributed.

Farm level

Soil characteristics. Soil samples, to a depth of 30 cm, from each 'soil type' identified by the farmer on his or her farm, were analysed for chemical and physical characteristics, according to Hinga *et al.* (1980) and Legger (1978).

Most farms show soil-N values below and soil-P values above the threshold level (Table 3). Moreover, the variability among farms is much higher for P than for N. Such a combination of N- and P-contents is typical for situations where soil fertility management to a large extent revolves around application of animal manure: nitrogen is very mobile in the system and susceptible to losses during storage and application of manure. Hence, a large proportion of the nitrogen in animal manure is lost before and during application, and therefore hardly contributes to the soil nitrogen store. Phosphorus on the other hand is far less susceptible to losses, and a substantial proportion of the element contained in animal manure therefore accumulates in the soil (Sharpley *et al.*, 1996). Soil potassium levels are, with the exception of those in Kasikeu, well above the threshold on most farms in the research clusters. Soil organic carbon levels are again variable and on the majority of the farms well below the level considered 'adequate' from an agronomic point of view.

Soil nutrient management. Current soil fertility management practices in the farming systems in the semi-arid areas in Kenya result in slightly negative nutrient balances (Table 4). The losses, however, represent only a very small proportion

Table 1 Major characteristics of the farming systems in the research clusters

	Matuu	***Kasikeu***	***Kibwezi***	***Kionyweni***	***Kiomo***	***Enkorika***
Farm households selected (no.)	28	19	17	26	13	8
Farming system characterisation	Rainfed + irrigated farming local cattle, maize, beans, sorghum	Rainfed farming maize, pigeon pea, beans, cowpea	Rainfed + irrigated farming, pigeon pea, cowpea, sorghum	Rainfed farming cross-bred cattle, maize, beans, fruit trees	Rainfed farming maize, beans, sorghum, millet, pigeon pea	Rainfed farming free ranging cattle, maize, beans
Average annual rainfall (mm)	600	700	560	600	600	500
Population density (persons km^{-2})	404	214	282	282	43	20
Soils	Alfisols Acrisols	Ferralsols	Alfisols	Alfisols Acrisols	Alfisols	Vertisols Alfisols
Average area per farm (ha)	1.5	2.8	3.5	2.3	6.7	51.6
Cultivated area per farm (ha)	1.3	1.6	1.7	1.7	3.4	1.0
Livestock per farm (TLU[1])	6.1	5.2	0.8	6.2	6.8	28.4
Distance to market (km)	8.4	1.2	1.5	5.4	3.5	35.6
Female headed households (%)	0	16	6	19	15	13

[1]TLU is a Tropical Livestock Unit, a hypothetical animal of 250 kg live weight, used to bring different animal types under the same denominator.

Table 2 Long-term average and actual annual precipitation (mm) and its temporal distribution during the monitoring period in the research clusters in the period 1999–2001

	Matuu	*Kasikeu*	*Kibwezi*	*Kionyweni*	*Kiomo*	*Enkorika*
Monitoring period	4/99–3/00	4/99–3/00	6/99–5/00	9/00–8/01	10/99–9/00	11/00–10/01/
Monitoring seasons[1]	LR99;SR99/00	LR99;SR99/00	LR99;SR99/00	SR00/01;LR01	SR99/00;LR00	SR00/01;LR01
Long-term average precipitation	600	700	560	600	600	500
Actual precipitation	525	755	58	188	425	259
% of long-term average	88	108	10	31	71	52
Distribution over year:						
January	0	0	0	4	66	2
February	0	0	0	0	6	0
March	1	110	0	55	13	3
April	62	12	0	112	160	43
May	1	26	0	0	0	7
June	2	19	0	15	0	3
July	1	35	0	2	0	0
August	3	28	0	0	12	10
September	0	30	0	0	33	0
October	68	20	7	0	34	0
November	287	340	40	0	19	131
December	100	135	11	0	81	60

[1]SR – short rains (from October to February); LR – long rains (from March to August).

of the total soil nutrient stocks, especially for phosphorus and potassium.

Nutrient flows into and out of the farm are generally low (all clusters represent low external input agricultural systems), but considerable variability exists among the studied research clusters (Table 5). In the subsistence-oriented clusters (Kionyweni, Kiomo and Enkorika) hardly any external nutrients enter the farm and small losses are observed through leaching. In Kionyweni and Kiomo, nutrients are imported through cattle grazing common land and/or crop residues after harvest, and manure being collected in the stable where cattle are kept during the night (Mohamed Saleem, 1998). In the clusters with irrigated agriculture and in Kasikeu, some mineral fertilisers are imported into the farm, while nutrients are exported in sold produce. Import of these external nutrients results in much higher leaching losses.

Use of mineral fertilisers and import of organic materials (animal feeds) correlated positively and significantly with crop yields and crop returns (0.48, 0.41 and 0.05 for N, P and K, respectively) and degree of market-orientation of the farm (marketed proportion of crop products and distance to market; 0.60, 0.38 and 0.19 for N, P and K, respectively). This indicates that due to the relatively high price of fertilisers and the high risks of crop failure in the rainfed systems, use of mineral fertilisers is restricted to the market-oriented farms with access to irrigation facilities.

Financial performance. Average net farm income levels were low, resulting in 35–85% of the farm households living below the poverty line, depending on research location (Table 6). Apart from Kibwezi (40% hired labour), the farm household members provided all the labour. Labour productivity is low, especially in the subsistence-oriented farming systems. Off-farm income played an important role in the total family earnings in Kasikeu, Kibwezi and Kiomo with contributions to family income of over 60%. In the more remote locations, opportunities for off-farm income were very limited. Net farm income

Table 3 Average soil characteristics in the research clusters; between parentheses percentages of farms in sample below threshold[1] level

	Matuu	*Kasikeu*	*Kibwezi*	*Kionyweni*	*Kiomo*	*Enkorika*
Total carbon (%)	0.80 (100)	0.56 (100)	0.45 (100)	0.55 (100)	1.24 (62)	1.27 (62)
Total nitrogen (%)	0.10 (82)	0.16 (37)	0.11 (88)	0.06 (100)	0.10 (100)	0.09 (75)
Total phosphorus (%)	0.12 (0)	0.01 (84)	0.05 (0)	0.24 (0)	0.03 (8)	0.19 (0)
Total potassium (%)	0.23 (32)	0.17 (79)	0.32 (0)	0.51 (0)	0.28 (15)	0.55 (0)
Clay fraction (%)	43.9	18.1	19.5	37.0	27.0	27.6
C/N ratio	7.6	4.1	5.3	9.6	13.5	16.2
Bulk density (kg, dm^3)	1477.3	1121.3	1300.0	1510.0	1200	1510.0

[1]These values have been defined as 'agronomically adequate' (Legger, 1978).
Threshold levels for:
- organic carbon 1.5%;
- nitrogen 0.12%;
- phosphorus 0.02%;
- potassium 0.20%.

levels were higher in the partially intensive, more market-oriented farming systems in Matuu and Kasikeu. The extremely low rainfall in Kibwezi in the first monitoring season negatively influenced income levels. Poverty levels were considerably higher in the subsistence-oriented farming systems in Kionyweni, Kiomo and Enkorika.

Crops

Maize (pure stands and inter-cropped), various vegetables, pasture and fallow are the most important forms of land use in the farming systems in the various research clusters. Maize is the common subsistence crop and showed considerable variation in yields among farms, clusters and seasons. The high risk of crop failure due to low and erratic rainfall is illustrated by the high proportion of non-harvested crops (Table 7). Yields of maize and maize/beans were highest in Matuu, mainly because some farmers applied water from the small-scale gravity irrigation system. Hardly any fertilisers, neither mineral nor organic, were applied on maize, with Kibwezi cluster as the only exception. This fertility management results in general in low yields, negative nutrient balances and very low financial results. The irrigated vegetables show a different picture with slightly higher mineral fertiliser rates, yields and financial returns.

Livestock

With a few exceptions, livestock management was of poor quality, with little or no attention for feed supply, including composition of the feed ration and manure management. Some of the most relevant consequences are inefficient

Table 4 Average farm level soil nutrient stocks (0–0.3 m) and annual flows in the research clusters in the period 1999–2001 (standard deviation between parentheses)

	Matuu (n = 28)	*Kasikeu* (n = 19)	*Kibwezi* (n = 17)	*Kionyweni* (n = 26)	*Kiomo* (n = 13)	*Enkorika* (n = 8)
N-stock (kg ha^{-1})	3016 (703)	6857 (4077)	4077 (5407)	1828 (479)	3596 (629)	2770 (1445)
Net N-flow (kg ha^{-1} $year^{-1}$)	−14 (14)	−15 (28)	−7 (26)	−1 (19)	−4 (7)	−8 (5)
N-flow (% of stock $year^{-1}$)	−0.5	−0.2	−0.2	−0.1	−0.1	−0.3
P-stock (kg ha^{-1})	3825 (3041)	449 (976)	1797 (838)	7211 (2452)	1403 (1042)	5865 (4021)
Net P-flow (kg ha^{-1} $year^{-1}$)	−1 (7)	2 (6)	0 (4)	−4 (4)	0 (1)	−2 (3)
P-flow (% of stock $year^{-1}$)	0.0	+0.4	0.0	−0.1	0.0	0.0
K-stock (kg ha^{-1})	6931 (3922)	6115 (2717)	11,866 (3754)	15,563 (6137)	9151 (2981)	15,709 (9300)
Net K-flow (kg ha^{-1} $year^{-1}$)	−14 (23)	0 (18)	−4 (11)	−1 (14)	−1 (8)	−3 (7)
K-flow (% of stock $year^{-1}$)	−0.2	0.0	0.0	0.0	0.0	0.0

Table 5 Average annual farm level nitrogen flows for the research clusters in the period 1999–2001 (in kg ha^{-1} year^{-1}; standard deviation between parentheses)

	Matuu (n = 28)	*Kasikeu* (n = 19)	*Kibwezi* (n = 17)	*Kionyweni* (n = 26)	*Kiomo* (n = 13)	*Enkorika* (n = 8)
Mineral fertiliser	5 (10)	5 (9)	9 (10)	1 (2)	0 (0)	0 (0)
Organic inputs	7 (8)	5 (9)	3 (4)	1 (1)	1 (1)	0 (0)
Grazing off-farm	1 (5)	5 (10)	5 (11)	13 (18)	9 (14)	0 (0)
Atmospheric deposition	3 (0)	4 (1)	1 (0)	2 (0)	3 (0)	2 (0)
Biological fixation	13 (12)	4 (4)	1 (1)	4 (4)	1 (1)	1 (2)
Crop/livestock products	−16 (23)	−5 (9)	−8 (6)	0 (1)	0 (0)	0 (0)
Crop residues	0 (1)	−2 (4)	0 (0)	0 (0)	0 (0)	0 (0)
Manure droppings off-farm	0 (2)	−2 (5)	−3 (5)	−6 (9)	−4 (6)	0 (0)
Leaching	−15 (6)	−19 (16)	−12 (13)	−7 (10)	−7 (1)	−8 (4)
Gaseous losses	−4 (2)	−1 (2)	0 (2)	−2 (5)	−1 (1)	−1 (1)
Erosion	−1 (1)	−5 (5)	−2 (3)	−1 (2)	−4 (3)	−2 (3)
Human excreta	−7 (5)	−3 (3)	−1 (11)	−5 (6)	−2 (1)	0 (0)
Total	−14 (14)	−14 (27)	−7 (26)	0 (19)	−4 (7)	−8 (5)

recycling of crop residues and nutrient through animal manure, with evidently high losses. Collection, storage and application of manure appear rather haphazard, so that nutrient (especially nitrogen) losses (volatilisation, leaching) from the manure are high and the quality of the manure eventually applied to the soil is low in terms of nutrient supplying capacity (Lekasi *et al.*, 2001; Van Gemen, 1998). The monitoring data suggest that on the majority of the farms, manure accumulated in stables and manure heaps during the monitoring period. However, no actual observations on manure stocks were included, and (disposable) manure production is calculated on the basis of animal numbers and estimated time of stabling; hence these results are not reliable; moreover, the unfavourable rainfall conditions may have led to conservative behaviour of the farmers with respect to manure application, because of anticipated lack of response under drought conditions.

Participatory learning and experimentation

The farmers' groups decided to focus the experiments on various application levels and combinations of farmyard manure and types of mineral fertilisers on the most common crop in the area. In Table 8 the results of a selection of the experiments are presented.

The results show that the erratic rainfall conditions in these semi-arid areas seriously hamper design and implementation of appropriate soil fertility management techniques at farm level. During the diagnostic phase, many farmers were confronted with complete crop failures once or

Table 6 Average annual farm level financial performance indicators in the research clusters in the period 1999–2001

	Matuu	*Kasikeu*	*Kibwezi*	*Kionyweni*	*Kiomo*	*Enkorika*
Net farm income (KSh, year^{-1})[1]	172,400	61,800	−18,800	57,300	15,200	20,000
Returns to labour (KSh, day^{-1})	276	133	−21	79	29	19
Off-farm income (KSh, year^{-1})	9,600	80,700	41,300	0	56,500	0
Family earnings (KSh, year^{-1})	182,000	142,500	22,500	57,300	71,700	20,000
Farms below poverty line (%)	36	37	71	69	62	87
Off-farm share in family earnings (%)	5	57	184	0	79	0
Household net cash flow (KSh, year^{-1})	42,600	93,500	73,100	6,900	45,500	21,900
Market share (% of value crops)	24	13	78	1	2	0

[1]1US$ = 75 Kenyan Shilling (KSh).

Table 7 Performance characteristics of maize, maize-bean inter-crops and vegetables in the research clusters in the period 1999–2001 (standard deviation between parentheses)

Maize (no data for Enkorika)

Season[2]	*Matuu*		*Kasikeu*		*Kibwezi*		*Kionyweni*		*Kiomo*	
	LR99 ($n = 100$)	SR99/00 ($n = 61$)	LR99 ($n = 10$)	SR99/00 ($n = 14$)	LR99 ($n = 11$)	SR99/00 ($n = 5$)	SR99/00 ($n = 24$)	LR01 ($n = 16$)	SR99/00 ($n = 7$)	LR01 ($n = 6$)
% of plots with no yield	10	7	0	14	27	20	33	13	0	67
Yield (kg × 1000 ha^{-1})	2.9 (1.9)	3.0 (2.0)	1.7 (0.8)	1.9 (2.1)	0.3 (0.3)	1.6 (2.5)	0.7 (1.2)	0.5 (0.4)	0.4 (0.3)	0.2 (0.3)
Mineral fertiliser (N in kg ha^{-1})	0.4 (2.2)	1.2 (6.3)	8.9 (16.2)	7.8 (8.3)	0.2 (0.5)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)
Organic inputs (N in kg ha^{-1})	2.6 (7.5)	4.0 (13.1)	17.8 (36)	1.3 (3.0)	13.3 (41)	0.8 (1.5)	1.5 (1.2)	2.6 (5.5)	12.9 (30)	0.1 (0)
Total N-balance (kg ha^{-1})	−69 (45)	−68 (47)	−22 (39)	−49 (41)	1 (36)	−34 (46)	−41 (28)	−34 (24)	−5 (18)	−8 (7)
Gross margin (KSh × 1000 ha^{-1})[1]	43 (30)	44 (31)	13 (30)	32 (34)	−1 (8)	15 (25)	19 (25)	13 (9)	4 (4)	1 (5)

Maize/beans (no data for Kibwezi)

Season	*Matuu*		*Kasikeu*		*Kionyweni*		*Kiomo*		*Enkorika*	
	LR99 ($n = 61$)	SR99/00 ($n = 59$)	LR99 ($n = 21$)	SR99/00 ($n = 22$)	SR99/00 ($n = 67$)	LR01 ($n = 65$)	SR99/00 ($n = 32$)	LR01 ($n = 21$)	SR00/01 ($n = 10$)	LR01 ($n = 16$)
% of plots with no yield	0	2	5	18	6	3	0	57	40	44
Yield maize (kg × 1000 ha^{-1})	1.5 (0.9)	1.8 (1.3)	0.5 (0.5)	0.7 (1.3)	1.3 (2.2)	1.0 (2.8)	0.1 (0.1)	0.1 (0.1)	1.1 (1.1)	0.2 (0.4)
Yield beans (kg × 1000 ha^{-1})	1.2 (0.8)	1.2 (0.9)	0.2 (0.2)	0.3 (0.6)	0.5 (0.9)	0.3 (0.8)	0.1 (0.1)	0.1 (0.1)	0.7 (1.5)	0.2 (0.3)
Mineral fertiliser (N in kg ha^{-1})	0.1 (0.7)	0.8 (4.0)	5.3 (16.9)	2.0 (5.5)	0 (0)	0.4 (1.6)	0 (0)	0 (0)	0 (0)	0 (0)
Organic inputs (N in kg ha^{-1})	4.0 (4.2)	6.1 (10.5)	9.4 (20.9)	7.6 (16.6)	2.2 (3.9)	3.3 (5.3)	1.5 (3.0)	0.6 (0.7)	6.3 (8.1)	11.5 (22)
Total N-balance (kg ha^{-1})	−45 (21)	−54 (36)	−11 (36)	−24 (40)	−28 (81)	−43 (72)	−9 (6)	−7 (8)	−30 (34)	1 (14)
Gross margin (KSh × 1000 ha^{-1})[1]	58 (41)	65 (46)	8 (22)	17 (43)	42 (68)	35 (75)	3 (6)	1 (7)	38 (51)	8 (11)

Vegetables (fresh yields)

	Matuu	*Kibwezi*
Yield pepper/chilli (kg ha^{-1})	5910 (6060)	5440 (6750)
Yield eggplant (kg ha^{-1})	3180 (2620)	3670 (5060)
Yield okra (kg ha^{-1})	1450 (830)	4530 (5240)
Yield tomato (kg ha^{-1})	5560 (10,200)	9380 (11,400)
Mineral fertiliser (N in kg ha^{-1})	8	16
Organic inputs (N in kg ha^{-1})	2	4
Total N-balance (kg ha^{-1})	−40	−8
Gross margin (KSh × 1000 ha^{-1})	209	45

[1]1US$ = 75 Kenyan Shilling (KSh); [2]LR = long rains, SR = short rains.

Table 8 Impact of application of various combinations of organic and mineral fertilisers to different crops on yield, gross margin, partial N-balance, N-use efficiency (Nout/Nin) and Value Cost Ratio (VCR) in five research clusters (standard deviation between parentheses)

Research site, test crop (number of plots)	*Technology tested*		*Yield season 1 (kg ha^{-1})*	*Yield season 2 (kg ha^{-1})*	*Gross margin (KSh ×1000 ha^{-1} season^{-1})[1]*	*Partial N-balance[2] (kg ha^{-1} season^{-1})*	*Nout/Nin*	*VCR[3]*
Matuu, irrigated, maize ($n = 11$) 1 = SR 2000 2 = LR 2001	Farmers' practice (0 inputs)		2691 (1964)	1810 (1617)	24.1	−144	—	—
	5 t/ha FYM[4]		2236 (2009)	1410 (1491)	17.3	−98	3.96	−1.75
	130 kg/ha DAP[5] + 135 kg/ha CAN[6]		3409 (1486)	2060 (1723)	23.3	−93	2.55	0.87
	5 t/ha FYM + 135 kg/ha CAN		3014 (1715)	1800 (1373)	20.9	−72	2.00	0.40
	5 t/ha FYM + 135 kg/ha DAP + 135 kg/ha CAN		4236 (1766)	1880 (1553)	25.9	−60	1.64	1.19
Matuu, rainfed, maize, ($n = 7$) 1 = SR 2000 2 = LR 2001	Farmers' practice (0 inputs)		843 (796)	—	8.1	−49	—	—
	5 t/ha FYM		643 (648)	—	3.6	−27	3.96	−0.80
	130 kg/ha DAP + 135 kg/ha CAN		1371 (1055)	—	6.0	−7	2.55	0.68
	5 t/ha FYM + 135 kg/ha CAN		1020 (782)	—	4.0	7	2.00	0.24
	5 t/ha FYM + 135 kg/ha DAP + 135 kg/ha CAN		1586 (1068)	—	5.6	23	1.64	0.73
Kionyweni, rainfed, maize/ cowpea ($n = 11$) 1 = SR 2001 2 = LR 2002	Farmers' practice (variable)	Maize	1538 (879)	775 (878)				—
		Cowp	358 (344)	291 (225)	14.3	−48	—	—
	No inputs	Maize	1858 (1298)	775 (978)				
		Cowp	404 (306)	309 (206)	16.3	−54	—	1.68
	5 t/ha FYM + 42 kg/ha CAN	Maize	2367 (1349)	1195 (1062)				
		Cowp	525 (382)	464 (272)	18.6	−27	1.63	0.72
	20 t/ha FYM	Maize	2455 (1154)	1295 (993)				
		Cowp	638 (608)	464 (251)	13.4	57	0.57	0.61
	40 t/ha FYM	Maize	3092 (1579)	1545 (1179)				
		Cowp	767 (820)	527 (331)	8.4	175	0.35	1

(*Continued*)

Table 8 *Continued*

Research site, test crop (number of plots)	*Technology tested*	*Yield season 1 (kg ha^{-1})*	*Yield season 2 (kg ha^{-1})*	*Gross margin (KSh ×1000 ha^{-1} season^{-1})[1]*	*Partial N-balance[2] (kg ha^{-1} season^{-1})*	*Nout/Nin*	*VCR[3]*
Kasikeu, rainfed, maize ($n = 5$) 1 = SR 2001 2 = LR 2002	Farmers' practice (0 input)	1153 (873)	1368 (1067)	12.6	−27	—	—
	20 ton/ha FYM[8]	1801 (938)	2016 (573)	14.1	27	0.61	1.29
	40 ton/ha FYM[8]	2608 (2118)	2863 (855)	17.3	153	0.43	1.48
Kiomo, rainfed, maize ($n = 5$) 1 = SR 2001 2 = LR 2002	Farmers' practice (0 input)	500 (242)	—	5.0	−10	—	—
	100 kg/ha 20/20/0[7]	450 (175)	—	1.5	11	0.45	−0.16
	200 kg/ha 20/20/0	502 (52)	—	−1.0	29	0.28	0.00
	Farmers practice (6 ton/ha FYM)[8]	390 (534)	587 (300)	3.4	10	0.50	—
	20 ton/ha FYM[8]	427 (466)	898 (479)	1.7	53	0.19	0.45
	40 ton/ha FYM[8]	744 (713)	1016 (546)	−2.5	116	0.13	0.45
Kibwezi, irrigated, onions ($n = 3$) 1 = SR 2001	Farmers' practice (5 ton/ha FYM)	813 (81)	—	−25.0	10	n.a.	—
	5 ton/ha FYM + 100 kg/ha 20/20/0	1027 (122)	—	−23.7	23		1.43
	5 ton/ha FYM + 200 kg/ha 20/20/0	1345 (271)	—	−20.3	32		1.78
	5 ton/ha FYM + 300 kg/ha 20/20/0	3046 (645)	—	10.6	−6		4.96

[1]1US$ = 75 Kenyan Shilling (KSh).
[2]Difference between input of element from external sources and export in form of crop products.
[3]$VCR = P(O_{T1} - O_{TC})/P(I_{T1} - I_{TC})$ where P = Price; O_{T1} = Output treatment 1; O_{TC} = Output control; I_{T1} = Input treatment 1; I_{TC} = Input control.
[4]FYM = Farmyard manure; local quality.
[5]DAP = Di-ammonium phosphate; 18% N, 46% P_2O_5.
[6]CAN = Calcium ammonium nitrate; 26% N.
[7]Percentages of N, P and K, respectively.
[8]Treatment applied in first season; second season residual impact.

Table 9 Value cost ratio for various combinations of organic and mineral fertilisers in Matuu with different fertiliser price scenarios

Treatment	*Value cost ratio*		
	Actual price	*−10%*	*−20%*
5 Mg/h FYM	—	—	—
130 kg/ha DAP + 135 kg/ha CAN	1.58	1.88	2.33
5 Mg/h FYM + 135 kg/ha CAN	1.11	1.23	1.38
5 Mg/h FYM + 130 kg/ha DAP +135 kg/ha CAN	1.30	1.45	1.63

twice during the three-season period of monitoring activities. The results in Matuu, comparing irrigated and rainfed maize, show that incentives, in terms of financial returns, for application of manures and fertilisers dramatically increase when water availability is not constraining.

The experimental results also show that the negative nutrient balances, prevailing in the rainfed farming systems can be remedied by application of higher rates of FYM and/or mineral fertilisers. These higher rates have an immediate impact on crop yield in the season when applied. High rates of FYM (20 Mg ha^{-1} and more) in rainfed maize in Kasikeu and Kiomo showed substantial positive effects on yields and nutrient balances in the subsequent season and possibly even in the third and fourth seasons. Combinations of FYM and fertiliser ('integrated soil fertility management', Ayaga *et al.*, 2004) tend to give stronger yield responses than application of FYM or fertilisers alone, as also shown in the semi-arid West-African Sahel (Yamoah *et al.*, 2002). In consultation with the farmers in all clusters combinations of N and P fertilisers were applied, even though the soil analyses showed 'agronomically adequate' levels of soil P. From the experimental results it is thus not possible to identify the relative importance of the degree of limitation by the two elements.

The financial returns to fertiliser and manure application are low and almost all treatments in the rainfed crops show value-cost ratios (VCRs) below 2, the often-cited minimum value for adopting new and risky technology (Gerner & Harris, 1993). Thus, under the prevailing conditions in semi-arid Kenya, it is financially unattractive and risky to apply these higher rates of nutrients, despite their positive impact on yields and nutrient balances. Combinations of FYM and fertilisers appear to give better financial returns than either of the two alone. The financial returns to FYM, however, should be evaluated over at least four seasons. The most appropriate strategy for application of chemical fertilisers and FYM for a farmer in a given situation depends among others on cash and manure availability. However, rates of FYM application as in the experimentation are not feasible, because of insufficient availability of good quality manure. Labour may also be a serious constraint, especially when alternative (for instance off-farm) activities provide higher returns.

The unfavourable price ratio between inputs and outputs also seriously constrains the adoption of nutrient adding technologies in the semi-arid areas. For instance, in Kenya, farm-gate fertiliser prices are three to six times higher than in Europe (Sanchez, 2002). Even moderate reductions in fertiliser prices, for instance through reduced transaction costs and/or increased chain efficiency could result in significantly higher VCRs, rendering application of fertilisers much more attractive to farmers in semi-arid areas (Table 9).

Stakeholder consultations

During the two stakeholder consultations, the results of the diagnostic and experimental activities in the project were combined with the experiences, goals and aspirations of the major stakeholders in the ASAL to arrive at a set of research and development directions (Table 10).

A distinction was made between short-term and long-term measures. Since, despite serious efforts, the most relevant members of parliament did not attend these consultations, the participants decided to formulate a short policy brief for initiating their involvement in the discussions (Figure 2).

Discussion and Conclusions

Following some adaptations to deal with the specific characteristics of farming systems in the

Table 10 Research and development priorities, identified during stakeholder consultations

System characterisation	*Rainfed; low population density*	*Rainfed; high population density*	*Irrigated systems*
Clusters	Enkorika, Kiomo	Kionyweni, Kasikeu	Kibwezi, Matuu
Future threats	• Degradation of grazing land • Reduction of grazing area • Water availability and competition • Accessibility, weak infrastructure	• Slow nutrient depletion, low yields, low efficiency of inputs • Low productivity levels • High risks of drought and crop failures • Competition for labour • Limited opportunities for off-farm activities	• Soil quality decline • Water availability and competition • Marketing high value crops
Short-term objectives	• Conservation/maintenance of resource base • Maintain/improve economic viability of the system	• Gradual improvement of natural resource base • Secure livelihood rural population	• Improve livelihood of the rural population • Maintain and expand irrigated production system
Short-term measures	• Control livestock numbers • Improve animal health care • Increase local food production through water harvesting, use of manure and rotation	• Breeding and using improved cattle • Mono-cropping maize and dual purpose legumes • Application of Rock Phosphate • Efficient nutrient recycling through crop residues and manure	• Maintenance and management of small-scale irrigation systems • Reduce transaction costs: market information, physical infrastructure, marketing channels, cooperatives, micro-finance
Long-term objectives	• Multifunctional land use • Economic development of the region • Improved livelihoods of the population	• Improved livelihoods rural population • Improvement of natural resource base	• High intensity, sustainable production of high value commodities, production centre for local and export market • Improved livelihoods of population
Long-term measures	• Design of development plan for livestock-wildlife-tourist industry • Establishment of feedlots for high intensity beef production • Establishment of manure processing facilities • Infrastructure: feed grains and processed manure transport, marketing infrastructure meat • Ecological niche market development	• Introduction dairy breeds • Import of feed grains from high potential areas • Cultivation of mono-cultures of maize and grain legumes • Cultivation of forage legumes • Efficient manure management • Establishment milk marketing system • Infrastructure for transport feed grains	• Establishment of effective production-marketing chain in public-private partnership • Development of skills for all links in chain (production, quality control, transport, marketing)

POLICY BRIEF STAKEHOLDERS' WORKSHOP NUTSAL PROJECT

Facilitating Sustainable Livelihoods for Smallholder Farming Families in semi-arid areas in Kenya

AIM
Contribute to ***economically viable***, ***ecologically non-degrading*** and ***socially acceptable*** development opportunities for smallholder farming families in the semi-arid areas of Kenya.

WHEN NOTHING IS DONE
- The natural resources in this fragile environment will ***degrade*** due to unsustainable farm management practices by increasing numbers of smallholder farming families. This is demonstrated by declining yields, negative soil nutrient balances, declining soil fertility status, erosion, reduction in water resources, reduced vegetative cover and loss of biodiversity.
- Smallholder farming families will be trapped in a downward ***poverty*** cycle due to low and further declining incomes from farming activities and limited opportunities for generation of off-farm income.
- These processes may finally lead to ***out-migration*** of rural families leaving a degraded, and without interventions, further ***deteriorating landscape*** and putting pressure on other already highly populated rural and urban areas.

DEVELOPMENT OF SUSTAINABLE FARMING SYSTEMS
The workshop participants conclude that based upon the results of various participative research and development initiatives the following ***potential developments options*** for agriculture in semi-arid areas in Kenya can be identified:
- ***Intensification of livestock production*** (beef, milk and milk processing)
- Further development of ***mixed crop-livestock production systems*** (zero-grazing, optimising manure management, intensification of fodder production, legumes)
- Development of ***small-scale irrigation systems*** enabling expansion of ***high value crop production*** and ***product diversification***

CREATING AN ENABLING ENVIRONMENT
The workshop participants conclude that the agricultural development options for semi-arid areas in Kenya can only be implemented successfully with ***active participation of conscious and knowledgeable farming families*** in an environment which provides sufficient ***incentives, security and opportunities***. The latter requires specific attention, since the population in these areas is confronted with harsh and fluctuating bio-physical conditions and weak economic infrastructure. Therefore, the workshops participants ***recommend the local and national policy makers in Kenya*** to urgently take the following actions:
- Initiate the development of ***production chains*** for a number of potential ***commercial products*** (beef, milk, legumes, grains and horticultural products) specifically for semi-arid areas in Kenya with heavy involvement of key private stakeholders (input supply, producers, traders, retailers).
- Provide ***support*** to the initiated production chains in various forms such as:
  - Stimulate ***private sector investment*** in semi-arid areas through premiums and tax incentives.
  - ***Co-invest*** (with private sector) in key infrastructure, such as small-scale irrigation schemes, milk processing plants, milk cool chain, meat cold storage, distribution system, transport and organisation of outlet/collection points for transport to bigger markets.
  - Focused ***research, extension*** and development support
  - Monitoring chain efficiency (fertilizer prices, market distortions, losses)
  - Linking ***micro-financing*** institutions to chain- and community-based organisations and initiatives
- Implement a ***coherent national agricultural policy*** aimed at protection of the weak agricultural sector in semi-arid areas in Kenya against competition from world market (price policy, import tariffs, export subsidies, etc.).
- Facilitate private sector development in ***agricultural processing*** or economic activities outside agriculture, creating ***alternative employment opportunities.***

Figure 2 Policy brief

ASAL, the NUTMON methodology appeared an efficient tool for quantification of nutrient balances and financial performance at both farm and activity (plot) level in the arid and semi-arid areas of Kenya. Compared to the participatory learning and action research (PLAR; Defoer, 2000), which is also implemented in Kenya, the NUTMON approach allows estimation of hard-to-quantify flows of nutrients (which contribute to high nutrient losses from the farms) and integrates a financial impact analysis (crucial for adoption decisions by farmers). The participatory approach followed increased awareness and insight among farm households with respect to soil nutrient flows, crop nutrient deficiencies and nutrient depletion. These insights formed the basis for identification of the constraints and potentials for improving the situation.

Results of soil chemical analyses indicate that in general the soils in the region are of poor quality, with low total N and organic C contents and higher P and K-contents. These results suggest that, considering the relative abundance of P, presumably originating from animal manure, substantial amounts of animal manure must have been applied over the years, which, however, is not reflected in the C-content. This is because the organic components in the animal manure have been largely decomposed, under the relatively favourable conditions for microbial action, i.e. relatively high temperatures and sufficient moisture in the upper soil layer. Similar soil nutrient dynamics under the influence of long-term application of manure have been recorded elsewhere in Kenya (Kihanda *et al.*, 2005) and in arid regions in China (Hao *et al.*, 2004), whereas on sandy soils in the Netherlands where very high rates of animal manure have been applied in the 1970s and 1980s, extremely high values of total phosphorus have been monitored (Aarts *et al.*, 2000).

Monitoring for two seasons indicated that low and erratic rainfall in the semi-arid zone of Kenya is a major constraint to crop production. This is illustrated by the high incidence of total crop failures (f.i. 85% and 38% of the maize-beans plots in respectively Kionyweni and Kaskieu showed total crop failure during the monitoring period) and yield differences with irrigated plots. The natural resources are degrading as a result of slightly negative soil nutrient balances, associated with soil erosion, nitrogen volatilisation and leaching, resulting in declining soil fertility status and reduced vegetative cover. Smallholder farming families are under increasing pressure, due to low and declining incomes from agricultural activities, requiring income supplementation from off-farm activities, which leads to labour scarcity on the farm. Introduction of more sustainable production technologies, including soil and water conservation practices and more efficient crop residue and manure management practices, is labour-demanding and conflicts therefore with income-generation.

The experimental results show that in the common rainfed farming systems the problems of low yields and negative nutrient balances could be addressed by application of higher rates of FYM and/or fertilisers. However, the financial returns to fertiliser and manure application are low, which makes application of these higher rates unattractive and risky under these conditions, despite the positive impact on yields and nutrient balances. Combinations of FYM and chemical fertilisers appear to give better financial returns than either component alone. Where conditions are better, as in the case of irrigated vegetable production, where water and marketing constraints are alleviated, farmers immediately respond by changing farm management practices, including higher rates of mineral and organic fertilisers, resulting in higher and more stable yields and higher financial returns. It is therefore obvious that water harvesting techniques and increase in and improvement of simple small-scale irrigation systems are key issues in effectively addressing soil fertility management in the semi-arid areas.

The farming community in this area is at a high risk to become trapped in a downward poverty cycle that may force them eventually to out-migrate from these marginal rural areas, leaving a degraded and without interventions, further deteriorating landscape and increasing pressure on other already densely populated rural and urban areas. To break this negative spiral a number of specific policy measures are suggested (Abdulai & Hazell, 1999; Pender *et al.*, 1999):

- An active and coherent national agricultural policy is required, aiming at protection of the weak agricultural sector in the semi-arid areas of Kenya from the world market (price policies, import tariffs, export subsidies, etc.).
- Local and national policy makers should initiate and support development of production chains for a number of potentially commercially attractive products (horticultural products, beef, milk, legume grains).
- Private sector investment should be stimulated through premiums and tax incentives.
- Targeted research, development and extension activities should be supported.
- Micro-financing institutions should be established, preferably linked to chain- and community-based organisations and initiatives.

Such measures will lead to a much wider range of financially attractive technology options for implementation by smallholders. This is expected to result in more sustainable natural resource management practices and improved livelihoods in the semi-arid areas.

Acknowledgements

The authors acknowledge with gratitude the financial support by the European Commission (under the Agricultural/Livestock Research Support Programme II) and the Dutch Ministry of Agriculture, Nature Management and Fisheries. We also wish to thank the Director KARI for hosting and supporting this project. We are also most grateful to the extension officers in the then Ministry of Agriculture and Rural Development involved in the project and to the farmers for their enthusiastic participation in the project.

Correspondence

Any correspondence should be directed to Andre De Jager, Wageningen University and Research Centre, Agricultural Economics Research Institute, PO Box 29703, 2502 LS, Den Haag, The Netherlands (andre.dejager@wur.nl).

References

Aarts, H.F.M., Habekotté, B. and van Keulen, H. (2000) Phosphorus (P) management in the 'De Marke' dairy farming system. *Nutrient Cycling in Agroecosystems* 56, 219–229.

Abdulai, A. and Hazell, P. (1999) The impact of policy reforms and trade liberalization on fragile lands in Sub-Saharan Africa. In A. Knox McCulloch, S. Babu and P. Hazell (eds) *Strategies for Poverty Alleviation and Sustainable Resource Management in the Fragile Lands of Sub-Saharan Africa* (pp. 127–147). Feldafing: Deutsche Stiftung für internationale Entwicklung (DSE).

Anonymous (1994) *Strategic Plan for Cereals in Kenya (1993–2013)*. Nairobi: Kenya Agricultural Research Institute.

Ashby, J.A. (1990) *Evaluating Technology with Farmers; A Handbook.* Cali, Colombia: CIAT.

Ayaga, G., Kibunja, C.N., Kanyanjua, S.M., Gikonyo, E.W. and Wamae, D.K. (2004) Improving soil fertility through integrated nutrient management. *Conference Proceedings: Agricultural Research and Development for Sustainable Resource Management and Food Security in Kenya* (pp. 1–11). 11–12 November 2003. Nairobi, Kenya: Kenya Agricultural Research Institute.

Babu, S. and Hazell, P. (1999) Growth, poverty alleviation, and the environment in the fragile lands of Sub-Saharan Africa. In A. Knox McCulloch, S. Babu and P. Hazell (eds) *Strategies for Poverty Alleviation and Sustainable Resource Management in the Fragile Lands of Sub-Saharan Africa* (pp. 49–61). Feldafing: Deutsche Stiftung für internationale Entwicklung (DSE).

Bationo, A., Traoré, Z., Kimetu, J., Bagayoko, J., Kihara, J., Bado, V., Lompo, M., Tabo, R. and Koala, S. (2003) Cropping systems in the Sudano-sahelian zone: Implications on soil fertility management. *Syngenta Foundation Symposium on Sustainable Agriculture in the Sahel. Lessons and Opportunities for Action.* 1–4 December 2003. Bamako (Mali).

Debrah, S.K. and Nederlof, E.S. (2002) *Empowering Farmers for Effective Participation in Decision-Making*. IFDC Technical Bulletin T-65. Lomé: IFDC.

Defoer, T. (2000) Moving methodologies. Learning about integrated soil fertility management in sub-Saharan Africa. PhD thesis, Wageningen University, Wageningen.

Defoer, T. and Budelman, A. (eds) (2000) *Managing Soil Fertility. A Resource Guide for Participatory Learning and Action Research*. Amsterdam: Royal Tropical Institute.

De Jager, A., Onduru, D.D., van Wijk, M.S., Vlaming, J. and Gachini, G.N. (2001) Assessing sustainability of low external input farm management systems with the nutrient monitoring approach: A case study in Kenya. *Agriculture, Ecosystems and Environment* 69, 99–118.

Faught, W.A., Nadar, H.M. and Waweru, S. (1984) Verification trials: Means of measuring applicability and economic feasibility of experimental results. *East African Agricultural and Forestry Journal* 44, 190–197.

Gachimbi, L.N., de Jager, A., van Keulen, H., Thuranira, E.G. and Nandwa, S.M. (2002) *Participatory Diagnosis of Soil Nutrient Depletion in Semi-arid Areas of Kenya*. Managing Africa's Soils No. 26. London: International Institute for Environment and Development.

Gachimbi, L.N., van Keulen, H., Thuranira, E.G., Karuku, A.M., de Jager, A., Nguluu, S., Ikombo, B.M., Kinama, J.M., Itabari, J.K. and Nandwa, S.M. (2005) Nutrient balances at farm level in Machakos (Kenya), using a participatory nutrient monitoring (NUTMON) approach. *Land Use Policy* 22, 13–22.

Gerner, H. and Harris, G. (1993) The use and supply of fertilizers in Sub-Saharan Africa. In H. van Reuler and W.H. Prins (eds) *The Role of Plant Nutrients for Sustainable Food Crop Production in Sub-Saharan Africa*. Leidschendam: VKP.

Hao, X., Chang, C. and Li, X. (2004) Long-term and residual effects of cattle manure application on distribution of P in soil aggregates. *Soil Science* 169 (10), 715–728.

Hartemink, A. and van Keulen, H. (eds) (2005) Soil degradation in Sub-Saharan Africa. *Land Use Policy* 22 (special issue), 74.

Haverkort, B., van der Kamp, B. and Waters-Bayer, A. (1991) *Joining Farmers' Experiments: Experiences in Participatory Technology Development*. London: ITP.

Hinga, G., Muchena, F.N. and Njihia, C.M. (eds) (1980) *Physical and Chemical Methods of Soil Analysis.* Internal publication. Nairobi, Kenya. National Agricultural Laboratories, KARI.

Ikombo, B.M. (1984) Effect of farmyard manure and fertilizer on maize in semi-arid areas of Eastern Kenya. *East African Agricultural and Forestry Journal* 44, 266–274.

Jaetzold, R. and Schmidt, H. (1983) *Farm Management Handbook of Kenya. Vol. II/C: East Kenya. Natural Conditions and Farm Management Information*. Nairobi: Ministry of Agriculture and German Agricultural Team (GTZ).

Johnson, N.L., Lilja, N. and Ashby, J.A. (2003) Measuring the impact of user participation in agricultural and natural resource management research. *Agricultural Systems* 78, 287–306.

Jones, P.G. and Thornton, P.K. (2002) Spatial modeling of risk in natural resource management. *Conservation Ecology* 5 (2), 27. On WWW at http://www.consecol.org/vol5/iss2/art27. Accessed 28.10.04.

Kihanda, F.M., Warren, G.P. and Micheni, A.N. (2005) Effects of manure and fertilizer on grain yield soil carbon and phosphorus in a 13-year field trial in semi-arid Kenya. *Experimental Agriculture* 41, 389–412.

Legger, D. (1978) *Physical and Chemical Methods of Soil Analysis*. Nairobi: Kenya Soil Survey Report No. M17.

Lekasi, J.K., Tanner, J.C., Kimani, S.K. and Harris, P.J.C. (2001) *Managing Manure to Sustain Smallholder Livelihoods in the East African Highlands*. DFID Natural Resources Systems Programme. London: HYDRA Publications.

Lesschen, J.P., Stoorvogel, J.J. and Smaling, E.M.A. (2004) *Scaling Soil Nutrient Balances. Enabling Mesolevel Applications for African Realities*. FAO Fertilizer and Plant Nutrition Bulletin No. 15, FAO, Rome, Italy.

Mantel, S. and van Engelen, V.W.P. (1999) Assessment of the impact of water erosion on productivity of maize in Kenya: An integrated modelling approach. *Land Degradation & Development* 10, 577–592.

Martin, A. and Sherington, J. (1997) Participatory research methods—implementation, effectiveness and institutional context. *Agricultural Systems* 55, 195–216.

Mohamed Saleem, M.A. (1998) Nutrient balance patterns in African livestock systems. *Agriculture, Ecosystems and Environment* 71, 241–254.

Okalebo, J.R., Simpson, J.R., Probert, M.E., Okwach, G.E. and McCowan, R.L. (1996) Maintenance of soil fertility under intensive maize cropping in Machakos District, Kenya. *Proc. 15th Annual General Meeting Soil Science Society of East Africa (SSSEA)*, 55–62.

Okwach, G.E. and Simiyu, C.S. (1999) Effects of land management on runoff, erosion and crop management in a semi-arid area of Kenya. *East African Agricultural and Forestry Journal* 65, 125–142.

Onduru, D., de Jager, A., Gachini, G. and Diop, J-M. (2001) *Exploring New Pathways for Innovative Soil Fertility Management in Kenya*. Managing Africa's Soils No. 25. London: International Institute for Environment and Development.

Pender, J., Place, F. and Ehui, S. (1999) Strategies for sustainable agricultural development in the East African Highlands. In A. Knox McCulloch, S. Babu and P. Hazell (eds) *Strategies for Poverty Alleviation and Sustainable Resource Management in the Fragile Lands of Sub-Saharan Africa* (pp. 148–204). Feldafing: Deutsche Stiftung für internationale Entwicklung (DSE).

Pretty, J.N. (1995) Participatory learning for sustainable agriculture. *World Development* 23 (8), 1247–1263.

Rukandema, M. (1984) Farming systems of semi-arid Eastern Kenya. A comparison. *East African Agricultural and Forestry Journal* 44, 422–434.

Sanchez, P.A. (2002) Soil fertility and hunger in Africa. *Science* 295, 2019–2020.

Scoones, I. (ed.) (2001) *Dynamics and Diversity: Soil Fertility and Farming Livelihoods in Africa. Case Studies from Ethiopia, Mali and Zimbabwe.* London: Earthscan Publications Limited.

Sharpley, A.N., Daniel, T.C., Sims, J.T. and Pote, D.H. (1996) Determining environmentally sound soil phosphorus levels. *Journal of Soil and Water Conservation* 51, 160–166.

Slingerland, M., van Rheenen, T. and Nibbering, J.W. (1998) Animal production and rural financing: The case of Zoundwéogo Province, Burkina Faso. *Quarterly Journal of International Agriculture* 37, 180–200.

Stephens, W. and Hess, T.M. (1999) Modelling the benefits of soil water conservation using the PARCH model—a case study from a semi-arid region in Kenya. *Journal of Arid Environments* 41, 335–344.

TAC Secretariat (1993) *CGIAR Medium Term Resource Allocation 1994–98.* Rome: FAO.

Tiffen, M., Mortimore, M. and Gichuki, F. (1994) *More People, Less Erosion: Environmental recovery in Kenya*. Nairobi: CTC Press.

Vlaming, J., van den Bosch, H., van Wijk, M.S., de Jager, A., Bannink, A. and van Keulen, H. (2001) *Monitoring Nutrient Flows and Economic Performance in Tropical Farming Systems (NUTMON). Part 1: Manual for the NUTMON-Toolbox*. Wageningen/Den Haag: Alterra/LEI.

Van Gemen, L.S. (1998) *Nutrient Losses During Manure Storage. A Study on Nutrient Losses from Stored Manure Under Different Cattle Management Systems in Three Kenyan Highland Districts.* MSc thesis, Soil Fertility and Plant Nutrition Group, Wageningen Agricultural University.

Woomer, P.L., Mukhwana, E.J. and Lynam, J.K. (2002) On-farm research and operation strategies in soil fertility management. In B. Vanlauwe, J. Dells, N. Sanginga and R. Merckx (eds) *Integrated Plant Nutrient Management in Sub-Saharan Africa: From Concept to Practice* (pp. 313–331). London: CABI.

Yamoah, C.F., Bationo, A., Shapiro, B. and Koala, S. (2002) Trend and stability analyses of millet yields treated with fertilizer and crop residues in the Sahel. *Field Crops Research* 75, 53–62.

Chapter 8 Farmers Field Schools and Integrated Nutrient Management in Kenya

De Jager, A., Onduru, D.D., Gachimibi, L.N., Muchena, F., Gachini, G., Van Beek, C.L.

Farmers Field Schools for Rural Empowerment and Life-long Learning in Integrated Nutrient Management: Experiences in Central and Eastern Kenya.

Yet to be submitted.

Farmers Field Schools for Rural Empowerment and Life-long Learning in Integrated Nutrient Management: Experiences in Central and Eastern Kenya

De Jager, A.[1], Onduru, D.D[2]., Gachimibi, L.N[3]., Muchena, F[2]., Gachini, G[3]., Van Beek, C.L.[4]

[1] Wageningen University and Research Centre – Agricultural Economics Research Institute (LEI), P.O. Box 29703, 2502 LS, Den Haag, The Netherlands
[2] ETC-East Africa, P.O. Box 76378, Nairobi, Kenya
[3] Kenya Agricultural Research Institute (KARI) – National Agricultural Research Laboratories (NARL), P.O. Box 14733, Nairobi, Kenya
[4] Wageningen University and Research Centre - Alterra, P.O. Box 47, 6700 AA Wageningen, The Netherlands

Abstract

In Africa, maintenance and improvement of soil fertility is considered one of the major factors to attain food security, reduce poverty and address environmental degradation. Research, extension and development programmes have had restricted impact in changing soil fertility management practices, while on the other hand various isolated successes have been recorded. The objective of this paper is to assess whether Farmer Field Schools (FFS) are an appropriate approach to effective innovation process on soil fertility management in East Africa. The results of a 4-year pilot project in Central and Eastern Kenya show that learning and innovation processes in FFS have a positive impact on the knowledge, skills and participation in experimentation/innovation processes of the members. Adoption of the tested technologies by the farm households was selective, but relatively high. The major adaptations made in the FFS approach compared with the original IPM-FFS (long-term group process, flexible type and frequency of activities, on-farm experimentation in addition to experimentation on central learning plot, no initial grants) appear to be appropriate for addressing soil fertility management in more complex African farming systems. However, it appeared that implementing joint commercial activities was the dominant driving force for sustaining the group process. The aspects of strengthening farmers' organisations and institutions, linking farm households to markets, general empowerment of rural people and experimental learning combined in an FFS approach, provides all the necessary ingredients for a sustainable and effective farmer-led process of innovation in smallholder agriculture in East Africa. Up-scaling of the experiences and the required facilitating conditions are priority issues to be addressed by national policy makers and the international development community.

Introduction

Much of the improvement in human welfare over the past century can be accounted for by technological developments (by practitioners as well as scientists) in public health, nutrition, and agriculture (UN Millennium Project, 2005a; IAC, 2004). These technical innovations contributed to reduced mortality rates and increased life expectancy and agricultural productivity. However, a large part of the world population still lives in poverty, suffers from hunger and diseases, lacks shelter, is excluded from economic and social progress. Global plans to eradicate poverty and promote gender equality, education and environmental sustainability are still being made (UN Millennium Project, 2005b). Hence, effective innovation processes which should encompass more than technological developments alone and need to be accompanied by well-designed measures for learning, capacity building, diffusion, transfer, commercialization and institutionalisation, require further development and implementation (Cantner and Pyka 2001; Kim and Nelson, 2000).

In Africa, maintenance and improvement of soil fertility is considered one of the major factors to attain food security, reduce poverty and address environmental degradation (Sanchez et al., 1997). While formal agricultural research has generated extensive of knowledge and fundamental insights in various aspects of soil fertility management and improved technologies have been developed, application of these results by farmers has remained below expectations. The prevailing extension approaches, that lacked the capacity to stimulate farmers to assess technologies critically, make adaptations to their specific conditions, learn how to further develop them and assisting farmers in organisational aspects, have contributed to these low adoption rates. Within the diversity and variability of the environments of rain-fed farming systems in Africa, farmers already have a wide body of knowledge in addressing soil fertility problems. Research and development programmes should build upon these experiences and further develop farmers' expertise and strengthen their decision-making and action taking capabilities that are (a) informed by principles and methods and (b) aided by instruments and tools that have been developed through science-linkages.

Currently Integrated Nutrient Management (INM) is the approach widely used by the science and development community to combat soil fertility decline in Africa and aims at the 'best' combination of available nutrient management technologies, i.e., those that are biophysically relevant, economically attractive and socially acceptable (Smaling et. al. 1996; Vanlauwe et al., 2002). Other common terminologies describe closely related approaches: Integrated Soil Fertility Management (ISFM) defined as 'The development of adoptable and sustainable soil management practices that integrate the biological, chemical, physical, social, cultural and economic processes that regulate soil fertility' (CIAT, 2006) and the slightly broader Integrated Soil, Water and Nutrient Management (ISWNM; Hughes and Venema, 2005). All aim to move away from reliance on uniform science-driven prescriptions of mineral fertilisers as the only solution to Africa's problems and seek to integrate science with local stakeholders' creativity in seizing opportunities provided by their local situation.

To address shortcomings in extension work on Integrated Pest Management (IPM), the Farmer Field Schools (FFS) approach was successfully developed in Indonesia by FAO's IPM programme in South East Asia. Where IPM is about bugs, INM is about nutrients. Just as the bugs in IPM are an entry point for a totally different approach to innovation in small-scale irrigated rice production, INM is an entry point for a different approach to innovation and development in African rainfed smallholder production systems. The development of FFS addressing INM combines (a) a technical focus on a locally feasible and sustainable mix of nutrient management strategies, and (b) a developmental and institutional focus on farmer creativity in capturing local opportunities for improving the profitability of farming.

The objective of this paper is to evaluate whether FFS with a focus on long-term farmers' organisation, experimentation and learning is an appropriate approach to an effective innovation process for soil fertility management in East Africa. This is done using results of a 4-year pilot project in Central and Eastern Kenya. In addition the paper aims at contributing to the on-going search for appropriate and effective models of farmers' platforms, such as the different types of FFS in CIP initiated programmes (Van der Fliert and Braun, 2002) or local agricultural research committees (Braun et al., 2002).

Farmers Field Schools: an evolving approach

The FFS approach was initially developed in Asia in the early 1990's to address a major threat to food security resulting from dramatic yield losses caused by the brown planthopper (Pontius et al., 2002). FFS is a learner-centred approach, whereby farmers through observation, experimentation and evaluation, leading to understanding, are equipped to address challenges and introduce appropriate changes in their farm management practices. Farmers are the main actors in this process and outsiders (extension agents, researchers, NGOs) take a role as facilitators or resource centres. Technical details and experiences in the implementation of FFS in IPM have been extensively documented (Kenmore, 1991; Van der Fliert, 1993; Matteson et al., 1994; Röling and Wagenmakers, 1998; Rola et al., 2002; Davis, 2006). Over the years, the FFS approach has been extended to include other technical issues in agriculture and rural development, such as natural resource management, animal husbandry, conservation agriculture, HIV/AIDS, food security and nutrition (FAO/FARM, 1998; Minjauw et al., 2002; LEISA Magazine, 2003; CIP/UPWARD, 2003; Onduru et al., 2003). More recently FFS are being considered an appropriate vehicle for general empowerment of rural actors, in which life-long learning processes, strengthening of local institutions and networks, stimulating social processes and collective actions may lead to improvement in rural livelihoods (Hounkonnou et al., 2004).

The FFS approach and adult learning processes are triggering yet another paradigm shift in the agricultural knowledge system, building upon two earlier major shifts: from a commodity to a (farming) systems approach and from the linear research-extension-farmer model to dynamic models of technology generation with various degrees of stakeholders' (farmers and others) participation in planning, design and implementation. FFS basically build upon these approaches by embracing the dimension of collective action and farmers' groups and therefore, the required strengthening of farm-level institutions.

Debates about the impacts of the FFS approach and the options for large-scale implementation have emerged as a result of the conclusions from a number of impact and evaluation studies. Three studies funded by the World Bank evaluating the impact of IPM-FFS programmes in the Philippines and Indonesia concluded that the FFS programmes are fiscally unsustainable because of the high costs of substantial up-scaling, no long-term effect of the FFS on pesticides expenditure and yield in rice was observed and no diffusion of knowledge took place to neighbouring farmers (Feder et al., 2004a; Feder et al., 2004b; Quizon et al., 2001; Van den Berg, 2004). Others have criticized these studies in terms of methodology used and the fact that broader impacts such as adult education, social organisation and farmer empowerment were not taken into account (Braun et al., 2006; NARC, 2004; Bingen, 2003). Critical reviews are made on the 'one-size-fits-all' approach of FFS and call for a more flexible methodology depending on the local situation (Davis, 2006). On the other hand there is wide evidence of positive impacts of FFS approach on rural communities and sustainable agricultural development as long as the impact is not limited to knowledge diffusion and technology transfer alone (Tripp et al., 2004; Mancini, 2006; Friis-Hansen, 2005; Mutandwa and Mpangwa, 2004; Praneetvatakul and Waibel, 2006). However, a comprehensive impact assessment methodology still needs to be developed to cover the broader development impacts of FFS on empowerment, education, farmers' organisation, farmers-research linkages and social cohesion. Also comparative cost-benefit analyses of the FFS approach and other existing models for research and extension at national level are as yet lacking.

In Kenya the FFS approach was initially implemented in 1995 by the Ministry of Agriculture (MoA) and FAO, focusing on Integrated Production and Pest Management. Currently MoA considers FFS as one of the approaches to be incorporated in the research and extension system. In 2003 an estimated 1000 FFS and 250 facilitators were active and 34,000 farm households have participated in FFS activities focusing on arable crops, horticulture, livestock and soil management (FAO/ILRI/KARI, 2003; Abate and Duveskog, 2003; Bunyatta et al. 2005). In the area of soil fertility improvement, FAO initiated various FFS programme in Kenya, Uganda and Tanzania. Experiences presented by various implementing agencies and policy makers during a regional conference on FFS experiences in soil fertility management (Uganda, 2006; organised by FAO-WageningenUR), showed a huge variation in approaches, intensity and quality of the learning process and impacts.

The initial IPM-FFS approach requires considerable modifications to deal effectively with the much more complex issues of rain-fed subsistence agriculture in Africa, let alone having a sustainable impact on building farm-level institutions, rural development, poverty alleviation and livelihood issues. Based upon literature review and discussions with stakeholders the following modifications were adopted in the pilot programme:

- The simple, but rather rigid structure of the activities in the IPM-FFS, was replaced by a more flexible set of activities depending on the priorities of the FFS and the topics addressed;
- The one-cropping-season life cycle was replaced by the aim to establish permanent schools to address long-term challenges of soil fertility improvement and facilitating farmers' organisations;
- As much as possible use was made of the many already existing community groups in which farm household members were participating (Place et al., 2004);
- In addition to central-plot experimentation, on-farm experimentation was stimulated to capture diversity in farm systems and allow for individual adaptation of technologies;
- No initial grants were provided since it jeopardises the sustainability and up-scaling of the FFS approach and commercial activities to cover costs were stimulated;
- Systematic built-in monitoring and impact assessments was included in the plan of activities;
- Participation of policy makers at District and National level in the process was realised to facilitate future up-scaling of the approach.

Elsewhere other modifications have been made during implementation of FFS to suit the content and specific purposes. Innovations include among others, community-based selection of participants, training farmer facilitators and focus on self-confidence and leadership capacities (Braun et al., 2006)

Methodology

Kiambu and Mbeere District were selected to implement the modified FFS approach. Both districts face soil fertility decline, have experiences with the FFS approach, and are representative for major, but contrasting agro-ecological zones and farming systems. In each district a representative catchment was selected and community workshops organised to introduce the project, assess interest and willingness of farmers to participate and to identify existing groups or willingness to form new groups. In total, four pilot FFS were formed: Kamugi (30 farmers; 50% women) and Munyaka (31 farmers; 74% women) in Mbeere; Kibichoi (30 members; 40% women) and Ngaita (26 members; 56% women) in Kiambu. Kamugi and Munyaka were formed on the basis of existing community groups. An overview of trends and challenges in the agricultural sector in both districts was prepared based on secondary data. This was followed by base-line surveys at the four sites to describe and analyse the current farming system practices, to create understanding of farmer's soil fertility management practices, challenges and possibilities and capture farmers' farm management dynamics. Subsequently, all FFS members participated in a participatory diagnostic activity, using the NUTMON approach (Van Beek et al., 2004). The diagnosis of farm management activities covered only one cropping season (March – August 2002) to allow a quick and efficient diagnostic process. This approach results in soil nutrient balances per cropping season instead of the more commonly used annual balances. Results of the diagnostic activity were discussed at FFS level, and individual farm households were supplied with a diagnostic report on soil fertility management and economic performance indicators.

These activities formed the initial steps of the learning cycle of the FFS and were followed by a curriculum programme, conducted for 5 seasons, consisting of: experimental design sessions, central plot and individual farmer experiments, Agro EcoSystems Analysis (AESA; Gallagher, 2003), special topics sessions and group dynamic activities. The FFS held meetings every two weeks. Experimental design was an integrated process in which farmers, scientists and extension staff shared views and decided on options and methods for learning and experimentation. All FFS started experimentation on a central learning plot and continued in the subsequent seasons. These activities formed the centre of the FFS activities during their first year of the FFS. An experiment typically consisted of a paired-wise design with 2 to 4 treatments, including a control, on plots of 20-50 m^2. Simple hypotheses such as *'If we apply DAP when planting maize variety Cargil 4141, grain yields will increase because DAP improves crop nutrient status provided that rains are adequate, good quality seeds are planted and that planting takes place early in the season'* were formulated by the FFS and agreements made on implementation, meetings, observations, group regulations etc. Farmers also implemented experiments on their individual farm and reported their experiences in the FFS meetings.

Monitoring, observations and evaluation of the experiments were performed by the FFS participants, using a documented AESA-format and various pictorial and scoring tools. The FFS agreed upon the various indicators for observations such as yields, pest and diseases, leaf colour, plant health, soil moisture, weed incidence, plant vigour and labour. FFS members were encouraged to express yields, inputs, costs and benefits in quantitative terms. Based on the first season's experimental results, a new cycle of experimental design was initiated before the subsequent seasons. Furthermore, the FFS participants determined the curriculum for special topics during the season, jointly with the facilitators and resource persons (Table 1).

Soon after the start of FFS, members explored the possibilities of initiating commercial activities to generate income for the FFS and its individual members. Where necessary, the facilitators assisted the group members in planning and linking them to external resource persons or inputs suppliers. Although a graduation ceremony marked the end of the facilitated FFS period, that also served as the starting point for the continuation of farmer-led FFS, with only limited periodic backstopping from facilitators.

A one-day policy workshop was organised in each district to share results of the FFS approach with stakeholders and district level policy makers, resulting in an action plan to facilitate implementation of the FFS approach.

Table 1 Summary curriculum of special topics in FFS

Area	*Curriculum topics*
Integrated Nutrient Management	Soil properties and functions; Soil nutrient supply and deficiencies; Mineral fertiliser use; Green manure and Tithonia; Cover crops; Water harvesting; Composting; Manure management; Soil Organic Matter management; Biological sources of fertility (legumes, Rhizobium); Soil and water conservation practices; Agroforestry; Soil physical fertility; Mulching
Production aspects of specific crops	Cowpeas; Soybeans; Sweet potato; Climbing beans; Watermelon; (Grafted) fruit trees; Beans; Vegetables; Irish potatoes, Cassava; Kitchen gardening; Crop storage; Drip irrigation; Natural crop protection and pest management
Livestock management (general, feeding, housing, health, breeding)	Dairy goats, Cattle; Dairy cattle; Bee keeping and honey processing; Calf rearing; Poultry; Pigs; Feeding and feed preservation; Napier production; Rabbits.
General farm management	Farm planning; Record keeping; Tree nursery management; Organic farming and use of local farm resources; Tillage practices
Home economics	Cookery; Human nutrition/balanced diet; Fireless cookers; Cake baking; Juice/jam making; Soap making; Milking salve; Yoghurt preparation
Others	HIV/AIDS; Leadership and teambuilding

About one year after the graduation ceremony, an impact assessment was conducted by the facilitators to evaluate the contributions of the FFS approach and its activities towards sustainable improvement of livelihoods of small-scale farmers in the target areas in general and towards adoption of sustainable soil fertility management practices in particular. The assessment included both, a longitudinal (comparison before and after joining the FFS) and a latitudinal (comparison between FFS participants and non-FFS members) analysis. The assessment focused on the following impact factors: knowledge and skills, changed practices, farm level impacts and livelihood impacts. Discussions and interviews, using a semi-structured questionnaire, were held with individual FFS members in their own farms, as well as with all FFS members during a FFS meeting. A sample of non-FFS members was selected and interviewed to allow comparison with FFS members. Half of the non-FFS members was selected from within the village where the FFS activities were conducted and the other half from neighbouring villages. Non-FFS members were purposively sampled to ensure that FFS members and non-FFS members were comparable in terms of production resources (land size and number of animals). In total 80 FFS members and 31 non-FFS members were interviewed.

Results

Challenges in the research sites

The baseline survey showed that low and erratic rainfall is the major constraint to developing productive farming systems in Mbeere District. Furthermore, land degradation through soil erosion is evident in many parts of the district. Yields of major food crops (cereals, legumes and root crops) fluctuated over the last decade with a general trend of either declining or stagnating. Constraints to livestock production include inadequate feed supply during dry periods, poor animal health, low genetic potential and poor livestock management. In Kiambu District rainfall and land holdings per family have declined over the last decade. Major constraints are declining soil fertility and poorly developed marketing infrastructure. Livestock development is constrained by poor milk market infrastructure, lack of roughage during dry periods and costly inputs (veterinary services), resulting in declining trends in productivity and economic returns.

The characteristics of farm household involved in FFS, show that income levels, both on-farm and off-farm, are low in Mbeere District, with almost all households living below the poverty line of 1 $ per person per day (Table 2). But also in Kiambu District, 60-80% of the households are living below the poverty line. These figures may have been influenced by the extremely poor rainfall during the period of data collection. In Kiambu District, farming system are intensive and are dominated by maize-beans as food crops, coffee as cash crop and zero-grazing dairy cattle (on average 2.5 cattle per household) for milk production. Mbeere is characterised by a much more extensive farming system, dominated by maize-beans as major food crops and other rainfed cash crops such as tobacco and khat. Livestock comprises cattle (1 per household) and goats (4.5 per household) kept under semi-free range conditions. The milk production in Kaimbu leads to a much higher contribution of livestock to annual household income than in Mbeere. Although soil fertility decline is often mentioned as a serious threat to the sustainability of production, only in one site high negative nutrient balances for N and K were reported during the NUTMON survey (Tables 3 and 4).

Table 2 Characteristics of farm households involved in FFS (standard deviation in parenthesis)

	Kiambu		***Mbeere***	
	Kibichoi	**Ngaita**	**Munyaka**	**Kamugi**
Number of farm households in FFS	30	12	30	29
Number of household members	6.3 (2.4)	5.4 (2.1)	6.5 (1.8)	6.6 (2.1)
Average area cultivated (ha)	0.8 (0.5)	0.5 (0.2)	1.2 (0.8)	2.1 (3.1)
TLU[1]	4.0 (5.1)	3.0 (4.5)	1.1 (1.7)	1.8 (1.8)
Family earnings ($[2] farm^{-1} halfyear^{-1})	395 (569)	156 (517)	189 (150)	48 (220)
Off-farm income ($ farm^{-1} halfyear^{-1})	241 (352)	128 (261)	96 (147)	39 (68)
Off-farm income (% of family earnings)	61	82	51	81
HH below poverty line[3] (%)	80	67	100	97
Market orientation (% of produce sold)	52	46	22	31
Distance to market (km)	6	5	11	9

[1]TLU = Tropical Livestock Units
[2]1 US$ = Ksh75
[3]Poverty line = 1 US$ person^{-1} day^{-1}

Table 3 Average farm-level full and partial balances in kg ha^{-1} halfyear^{-1} and stocks in kg ha^{-1} (standard deviation in parenthesis)

	Kiambu		**Mbeere**	
	Kibichoi (n=30)	**Ngaita (n=12)**	**Munyaka (n=30)**	**Kamugi (n=29)**
Full N-balance	-2.6 (61.1)	-50.0 (81.2)	1.1 (12.0)	2.5 (17.6)
Full P-balance	36.7 (48.8)	5.9 (34.5)	-1.7 (2.4)	-0.9 (3.8)
Full K-balance	16.9 (80.5)	-28.2 (87.5)	-5.4 (17.7)	16.0 (21.4)
Partial N-balance	58.8(83.1)	24.9 (70.6)	-3.1 (15.9)	0.0 (19.1)
Partial P-balance	39.3(47.6)	9.8 (32.0)	-1.0 (2.4)	-1.5 (3.8)
Partial K-balance	43.1(71.6)	6.1 (53.5)	6.6 (16.2)	14.2 (21.9)
N-stock[1]	7268 (811)	8006 (717)	1830 (568)	2955 (749)
P-stock[1]	1978 (570)	2229 (286)	558 (217)	695 (203)
K-stock[1]	16068 (5777)	14569 (8420)	4854 (2197)	8299 (3397)

[1] Total N, P and K are used in the NUTMON model based on sample analysis of total N, available P and exchangeable K (Van den Bosch et al., 1998)

Table 4 Average farm-level N-flows per flow type in kg ha^{-1} half $year^{-1}$ (standard deviation in parenthesis)

	Kiambu		Mbeere	
	Kibichoi (n=30)	**Ngaita (n=12)**	**Munyaka (n=30)**	**Kamugi (n=29)**
IN 1 Mineral fertiliser	31.7 (34.9)	26.2 (41.3)	1.5 (4.2)	5.2 (21.5)
IN 1 Animal feeds (concentr)	32.5 (35.7)	15.0 (23.7)	0.2 (0.6)	0.1 (0.4)
IN 2 Organic fertilisers	14.6 (24.7)	13.9 (20.9)	0.7 (1.6)	0.3 (0.7)
IN 2 Organic animal feeds	10.6 (17.9)	4.9 (7.4)	0.0 (0)	0.0 (0)
IN 2 Grazing animals	0.0 (0)	0.0 (0)	12.7 (17.7)	20.0 (25.4)
IN 3 Atmospheric deposition	8.0 (0)	3.4 (0)	6.7 (0)	4.0 (0.7)
IN 4 Biological N fixation	3.6 (2.2)	3.1 (3.4)	11.3 (12.0)	4.2 (5.3)
OUT 1 Crop products	-12.5 13.5)	-10.7 (11.2)	-5.4 (8.7)	-0.8 (4.0)
OUT 1 Animal products	-6.8 (7.4)	-5.0 (5.3)	0.0 (0)	-0.0 (0)
OUT 2 Crop residues	-2.3 (6.9)	-7.6 (14.0)	-0.2 (0.4)	-4.5 (9.8)
OUT 2 Animal manure	0.0 (0)	0.0 (0)	-5.3 (5.8)	-8.2 (10.3)
OUT 3 Leaching	-33.7 (21.6)	-37.0 (20.1)	-4.3 (2.2)	-4.7 (2.1)
OUT 4 Gaseous losses	-20.8 (12.7)	-22.8 (11.9)	-1.2 (0.8)	-1.0 (1.0)
OUT 5 Erosion	-18.5 (14.8)	-21.7 (24.9)	-8.2 (8.1)	-0.1 (0.1)
OUT 6 Human excreta	-9.0 (6.5)	-11.7 (8.9)	-7.3 (10.2)	-12.0 (20.2)
Balance	**-2.6**	**-50.0**	**1.1**	**2.5**

The farms in Kiambu District import considerable quantities of nutrients in both mineral and organic fertilisers and in animal feeds. On the other hand non-productive losses through leaching (N, K), gaseous losses (N) and erosion are high. With slightly lower importation of external inputs, as is the case for the farms in Ngaita, balances for N and K are strongly negative. A focus on reductions in nutrient losses appears most appropriate for these farms. The extensive system in Mbeere is characterised by low imports of nutrients (only grazing outside the farm and nitrogen fixation bring nutrients in the farming system) and low crop production levels. It is obvious that the nutrient transfers from communal grazing has its limitations and to increase crop productivity other nutrient-adding technologies are required.

The baseline survey revealed a wide variation in soil fertility management practices being conducted on the different farms (Table 5). When monitoring soil fertility, farmers use a variety of indicators such as crop yields, soil colour, incidence of weeds, pests and diseases and signs of erosion. Members of the FFS have a wide social network and the majority participate in other social, self-help and church affiliated groups. In each village a total of 15-20 different groups were identified.

Table 5 Types of soil fertility management and water conservation technologies practised by farmers.

Group of technologies	***Identified technologies practised on-farm***
Fertilizer application	Broadcast, line and spot application
Manure application	Apply in furrows not covered with soil
	Apply in furrows covered with soil
	Apply in small hills not covered with soil
	Apply in small hills covered with soil
	Broadcast not covered with soil
	Broadcast covered with soil
Soil and water conservation	Fanya juu, Bench terraces, Cut off drains, Gulley control, River bank protection, Use of trash lines, Unploughed strips, Grass strips, Stone lines, Basins/9 seeds in a hole
Water harvesting	Contour bunds, Pitting, Road run-off harvesting, Semi-circular bunds
Others	Crop residues, composting, green manures, legumes, fallowing, mulching

In food crops, high costs of fertilizer and soil fertility decline, jointly with incidence of pests and diseases were considered major constraints, while in cash crops low product prices and poor roads (Mbeere) were mentioned most. Surprisingly, access to credit was not mentioned as a priority constraint in cash crop production. In livestock, the genetic potential of cattle (Kiambu) and goats (Mbeere), poor housing conditions, feed availability (quantity and quality) and manure management were given by the farmers as major constraints.

Experimentation, observation and learning

The majority of the experiments on the central plots in the FFS focused on food crops (maize, bean and cowpea) testing various combinations of organic and inorganic nutrient sources. In Kiambu, additional series of experiments with livestock were carried out, focusing on methods of feed production, feeding regimes and manure management. A summary of the experiments carried out in Kibichoi and Munyaka and its results are presented in Table 6 and 7 respectively.

The results of the experiments in the Kiambu District show no unequivocal picture. Application of DAP or TSP, in combination with manure and/or Tithonia on maize increased yields and financial returns. Also deep digging had a positive impact on yields and financial returns. The combination of DAP and Rhizobium application on local beans showed clear increases in yields and financial returns. In Napier the Tumbukiza system (8 canes planted per hole, 65 ton FYM ha^{-1} applied in the planting hole and 50 kg ha^{-1} TSP; Tumbukiza is a Kiswahili word meaning 'placing in a hole'), combined with an improved variety, increased the yield and financial returns and reduced the heavy nitrogen mining of this crop compared to the traditional system (one cane per hole, 10 ton FYM ha^{-1} and 50 kg ha^{-1} TSP).

In Kiambu, an experiment with manure storage in a pit, lined and covered with a polythene sheet was executed on 7 farms. After 11 weeks of pit manure storage, the concentration of K, Mg, Cu, Mn and Zn were, on average, higher than at the beginning of the storage, the percentage increase ranging from 1.5 to 53.5. However, at the end of the pit storage period, there were recorded losses of 1.7%, 6.8%, 2.7%, and 46.9% for nitrogen, phosphorus, calcium and iron respectively. These losses are lower than the 8%-40% nitrogen losses reported for open and heap storage methods at farm level for nitrogen (Kirchman, 1985). They were also lower than recorded N losses of about 40 % reported by Lekasi et al., (2001a; b) during storage and/or composting of uncovered manure/slurry heaps.

In Mbeere, combinations of manure and DAP with and without Tithonia showed positive impacts on yield and financial returns in maize, while the combination of TSP and Rhizobium application showed the same positive impacts in beans.

It is remarkable that farmers' rankings of preferred technologies for adoption generally correlate with yield levels rather than with financial returns. At both sites, DAP or TSP application in combination with organic manure results in Value-Cost-Ratio's exceeding 2, indicating short-term financial benefits. For Mbeere District this result is not in line with other on-farm research which showed that unfavourable rainfall distribution and input-output farm-gate price ratio's rendered most soil fertility improvement technologies financially unattractive (De Jager et al., 2005). Most of the tested technologies result in similar partial nutrient balances than current farmers' practices, but at higher physical and financial output levels.

Table 6 Summary of results of experiments on the central plot in Kibichoi, Kiambu District in the period 2002-2005 (standard deviation in parenthesis)

Treatments and crops	***Yield kg ha^{-1}***	***GM \$ ha^{-1}***	***B/C ratio***	***VCR[1]***	***N-bal[2] kg ha^{-1}***	***Mean FFS score[3]***
Maize 2002 SR[4] + 2003 LR[5] (n=8)						
Normal tillage	3958 (1971)	1013 (461)	3.3	-	17	5.2
Double digging	4729 (1161)	928 (210)	2.6	0.4	5	14.8
Maize: 2002 SR + 2003 LR (n=4)						
FYM[6] (18 t ha^{-1})	3709 (699)	848 (171)	2.5	-	33	8.2
DAP (120 kg ha^{-1})	5000 (2193)	1249 (441)	5.3	-	-89	3.1
FYM (18 t ha^{-1})+DAP (120 kg ha^{-1})	4917 (1708)	1030 (306)	2.7	0.2	33	4.7
FYM (18 t ha^{-1})+CAN (120 kg ha^{-1})	3750 (1664)	755 (317)	2.3	-0.7	66	4.0
Beans: 2003 SR (n=1)						
FYM (22 t ha^{-1})	1750 (-)	532 (-)	2.0	-	59	3.0
FYM + Rhizobium[7] (0.27 kg ha^{-1})	1500 (-)	392 (-)	1.7	-54.5	69	4.0
FYM+Rhizobium[7](0.27kgha^{-1})+DAP(105kgha^{-1})	2000 (-)	681 (-)	2.2	4.2	50	13.0
Maize: 2004 SR (n=2)						
Control (zero application)	5227 (321)	1320 (71)	7.5	-	-117	3.3
Tithonia (11 t ha^{-1})	8182 (857)	1795 (151)	7.1	6.4	-116	4.5
Tithonia (11 t ha^{-1})+TSP (120 kg ha^{-1})	8788 (1071)	1856 (191)	6.3	4.7	-128	5.5
Tithonia (11 t ha^{-1})+TSP+CAN (120 kg ha^{-1})	-[8]	-	-	-	-	6.7
Napier: 2004 LR+2004 SR+2005 LR[9](n=2)[10]						
Conventional tillage + Local variety	8925 (2928)	1220 (507)	5.3	-	-174	2.7
Conventional tillage + Kakamega1	13259 (220)	1561 (176)	6.4	-	-260	5.0
Tumbukiza tillage + Local variety	13691 (3557)	1108 (677)	2.0	0.9	-63	2.8
Tumbukiza tillage + Kakamega1	17308 (326)	1726 (341)	2.5	1.6	-157	9.5
Napier: 2005 LR[11] (n=6)[10]						
Cattle manure (10 t ha^{-1})	2073 (956)	60 (169)	1.2	-	-10	2.5
Cattle manure (10 t ha^{-1}) + slurry (11.7 t ha^{-1})	2487 (852)	26 (153)	1.1	0.7	-3	17.5

[1]VCR = (Gross Value Treatment–Gross Value Control)/(Variable Costs Treatment–Variable Cost Control)
[2]N-bal = Partial N-balance (IN1 +IN2 – OUT1 –OUT2)
[3]FFS-score = 20 points divided over treatments on preference of technology
[4]SR = Short Rains from October – February
[5]LR = Long Rains from March - August
[6]FYM = Farm Yard Manure
[7] No estimation of additional input in N-balance was made
[8] Due to shading of plot, unreliable yield data
[9] Data based on total of 3 cuts
[10] Napier dry matter yields
[11] Data based on 1 cut

Commercial activities and institutionalisation

In the second year of operation, all FFS initiated commercial activities with the objectives of generating income for the FFS to cater for costs and to test the viability of group-wise cash generating activities. The facilitators assisted in making contacts to acquire necessary inputs (seeds, materials), in formulating business plans and, where necessary, in making arrangements for short-term loans. The following activities were undertaken: growing water melon and Irish potatoes, milk processing and marketing (yoghurt) and keeping improved goat bucks. The generated cash was used to meet various group needs: buying farm inputs for continuing commercial activities, creating cash reserve in the group's bank account and paying for hired labour. In one school, a community member was employed to manage sales of processed milk products. The dairy goat up-grading scheme, using improved bucks, resulted in additional income for the FFS as well as improvement of goat herds in the surrounding villages. In addition to cash generation, the milk processing enterprise also provided group members with the opportunity to sell their milk at a higher price to the small-scale milk processing plant, thus bypassing the brokers. The Kibichoi group processed more than 100 bottles per week of fresh milk into yoghurt for sale in addition to selling fresh milk, cakes and running a tea kiosk.

Table 7 Summary of results of experiments on the central plot in Munyaka, Mbeere District in the period 2002-2005 (standard deviation in parenthesis)

Treatments and crops	*Yield kg ha^{-1}*	*GM \$ ha^{-1}*	*B/C ratio*	*VCR[1]*	*N-bal[2] kg ha^{-1}*	*Mean FFS score[3]*
Maize: 2002 SR[4] + 2003 LR[5] (n=2)						
FYM[6] (16t ha^{-1})	2530 (1017)	28 (122)	1.1	-	-22	4.0
DAP (216 kg ha^{-1})	2960 (1479)	185 (228)	1.7	-0.4	-22	4.5
FYM (16t ha^{-1})+ DAP (216 kg ha^{-1})	3741 (918)	114 (121)	1.3	2.2	-2	5.2
FYM(16tha^{-1})+DAP(216kgha^{-1})+Tithonia(3.6t ha^{-1})	4350 (772)	203 (114)	1.4	2.7	1	6.3
Beans: 2003 SR (Crop failure)						
Control	-	-	-	-	-	-
TSP (100 kg ha^{-1})	-	-	-	-	-	-
Rhizobium (0.27 kg ha^{-1})	-	-	-	-	-	-
TSP (100 kg ha^{-1}) + Rhizobium (0.27 kg ha^{-1})	-	-	-	-	-	-
Cowpeas: 2004 LR + 2004 SR (n=2)						
Control	1100 (115)	131 (28)	1.8	-	-38	4.8
Rhizobium[7] (0.17 kg ha^{-1})	1175 (206)	149 (53)	1.9	9.6	-40	4.8
TSP (104 kg ha^{-1})	1387 (322)	171 (86)	1.9	2.1	-48	4.8
TSP (0.17 kg ha^{-1}) + Rhizobium[1] (104 kg ha^{-1})	1700 (216)	253 (57)	2.3	4.2	-58	5.6

[1]VCR = (Gross Value Treatment–Gross Value Control)/(Variable Costs Treatment–Variable Cost Control)
[2]N-bal = Partial N-balance (IN1 +IN2 – OUT1 –OUT2)
[3]FFS-score = 20 points divided over treatments on preference of technology
[4]SR = Short Rains from October – February
[5]LR = Long Rains from March - August
[6]FYM = Farm Yard Manure
[7] No estimation of additional input in N-balance was made

Furthermore, the FFS have been registered with Government bodies in charge of community development programmes (Department of Social Services) to facilitate participation of the groups in rural development programmes. One year after the graduation and withdrawal of the regular facilitation, all four FFS were still operational, with regular meetings and experimental and commercial activities on the central plot.

Similar experiences in Uganda, initiated in the same project, show that FFS transformed themselves into officially registered Community Based Organisations (CBO's), with the original facilitators of the FFS only playing a backstopping roles. The groups continue to conduct experiments, exploit a commercial plot and are involved in 3-4 extension and rural development programmes (Zake et al., 2005).

Impact assessment

Knowledge and skills

Farm households that have participated in FFS activities have gained more knowledge on soil fertility management and are aware of more different types of management practices to address soil fertility decline than households, which have not participated in FFS (Table 8). Prior to joining the FFS, 75-90% of all farm households reported having conducted on-farm experiments. During the season of assessment, almost all FFS farm households were conducting one or more experiments on their individual farms, against 52% of the non-FFS farm households (Table 9). Also, FFS farm households engaged in more different types of trials in addition to the common crop variety testing and experiments on planting methods. The considerably lower share of the FFS members reporting to have conducted crop variety trials prior to joining the FFS (43%) compared to the non-FFS farmers in the past 3 years (81%) is difficult to explain. It could be that at the time of assessment, FFS farmers associated experimentation with soil fertility issues and 'forgot' regular experimentation with crop varieties. Although the evaluation results provide little information about the 'quality' of the learning process, observations during

FFS meetings give a positive impression. For instance the majority of the FFS members were able to explain important soil fertility processes such as the role of N, P and K in crop growth and how Rhizobium increases available nitrogen for the crops.

Table 8 Technologies perceived by farm households to address soil fertility decline, comparison between FFS and non-FFS members (% of farm households mentioning particular technology)

Technologies	***FFS (n=80)***	***n-FFS (n=31)***
Fertilizers (%)	76	81
Manure (%)	75	87
Terraces/grass strips (%)	50	48
Tithonia (%)	18	0
Compost (%)	35	0
Crop residues (%)	11	3
Crop rotation (%)	9	10
Double digging (%)	29	19
Green manure (%)	4	0
Agroforestry (%)	7	0
Mulching (%)	6	3
Lime (%)	3	10
Average number of technologies per farm	3.5	2.8

Table 9 Farm households conducting on-farm experiments on the individual farm, comparison over time for FFS members and non-FFS members (% of farm households conducting experiments)

	Before FFS/last 3 years		***After FFS/currently***	
	FFS (n=80)	***n-FFS (n=31)***	***FFS (n=80)***	***n-FFS (n=31)***
Farm households experimenting (%)	75	90	98	52
Av. number experiments per farm (no)	1.6	1.5	1.7	1.4
Type of experiment:				
Rhizobium (%)	0	0	24	0
Manure-fertilizer (%)	0	0	11	0
Fertilizer (+ridges) (%)	22	27	13	26
Tithonia (%)	0	0	10	0
Manure (%)	7	15	10	0
Crop varieties (%)	43	81	29	61
Planting method (%)	16	12	20	17
Double digging (%)	3	13	10	0
Composting (%)	8	4	5	0
Tumbukiza Napier (%)	0	0	22	0
Vegetables/spices (%)	0	0	10	19

Changed practices

All farm households reported changes in soil fertility management practices over the past 3 years, illustrating the dynamics of smallholder agriculture in the region (Table 10). The FFS farm households however, reported considerably more changes and more different types of adopted practices than the non-FFS households. Some of the technologies tested in the FFS were well adopted by individual members such as application of Rhizobium (75% of the farms) and Tithonia (45%) in Mbeere and double digging (65%) and Tumbikiza Napier (40%) in Kiambu District. Other technologies tested were not adopted by a large group of farmers such as Rhizobium in Kiambu (60% of the households because Rhizobium was not locally available and/or not economical) and TSP application in Mbeere (55% of the households because of unavailability and high costs). The FFS activities led also to other changes in management practices such as in livestock management and feeding (40-60% of the farms), record keeping (40% of the households in Kibichoi), and early planting. All farms reported changes in commercial, cash-generating activities with no difference between FFS and non-FFS members (Table 11). Vegetable production (kale, water melon, tomatoes) was an important new activity at all research sites. In Mbeere, fruits, goats and khat (*Catha edulis*) were specific common new activities and dairy cattle, goats and poultry keeping in Kiambu. The FFS-supported yoghurt- and cake/jam-making activities were adopted widely by farmers in Kiambu. The impacts of the FFS activities outside the group appear limited to the village where the school is located. Most farm households in neighbouring villages were aware of the existence of the FFS, but receiving information and adopting technologies originating from the FFS was rather limited (Table 12).

Farm level impacts
The majority (>90%) of the farm households reported higher production levels and financial returns as a result of the adoption of new soil fertility management practices. Adoption of new cash-generating activities contributed to increased income and food security. The additional income was mainly used for purchase of food items (mentioned by 60-80% of the households), for non-food items (25-30%) and for school fees (15-20%). Investments in agriculture (inputs, hired labour) were reported by 10-20% of the households in Kiambu and by 80% of the households in Kamugi (Mbeere).

Table 10 Soil fertility management practices adopted since FFS participation or (for non-FFS members) compared to 3 years ago for non-FFS members (% of farm households mentioning type of management practice)

Soil fertility management practices	***Kibichoi***		***Ngaita***		***Munyaka***		***Kamugi***	
	FFS (n=19)	***n-FFS (n=9)***	***FFS (n=19)***	***n-FFS (n=6)***	***FFS (n=25)***	***n-FFS (n=9)***	***FFS (n=17)***	***n-FFS (n=7)***
Rhizobium (%)	11	-	-	-	76	-	71	-
Manure (%)	63	56	26	50	64	56	47	57
Fertilizer (%)	68	44	63	67	48	67	53	57
Tithonia (%)	53	-	-	-	40	-	47	-
Manure-Fertilizer (%)	-	11	16	17	24	22	6	-
Crop residues (%)	-	-	11	-	20	-	6	-
Mulching (%)	11	11	32	-	12	-	-	-
Ridges (%)	-	-	-	-	4	33	-	-
Terraces (%)	32	11	16	-	8	33	6	71
Compost (%)	42	22	47	-	8	22	12	-
Double digging (%)	68	11	84	-	4	11	24	29
SWC[1] (%)	-	-	-	-	4	11	12	-
Tumbukiza[2] Napier (%)	11	-	42	-	-	-	-	-
Agro-forestry (%)	-	-	16	-	-	-	-	-
Crop rotation (%)	5	-	16	-	4	-	-	-
Planting method (%)	-	-	5	-	-	11	-	-
Av. number of practices per farm [3]	3.7	1.9	3.8	1.3	3.3	2.8	2.9	2.3

[1] Soil and water conservation practices
[2] See text for explanation
[3] Maximum of 4 practices per farm were recorded

Table 11 New commercial activities since FFS participation or (for non-FFS members) compared to 3 years ago for non-FFS members (% of farm households mentioning type of commercial activity)

Commercial cash-generating activities	***Kibichoi***		***Ngaita***		***Munyaka***		***Kamugi***	
	FFS (n=13)	***n-FFS (n=9)***	***FFS (n=9)***	***n-FFS (n=6)***	***FFS (n=25)***	***n-FFS (n=9)***	***FFS (n=17)***	***n-FFS (n=7)***
Farms with new activities (%)	100	100	100	100	96	89	82	86
Maize and/or beans (%)	15	11	11	-	50	-	57	-
Fruits (mango/pawpaw/passion) (%)	-	-	-	-	33	38	21	33
Livestock (poultry/goats) (%)	31	44	22	17	21	-	21	-
Butternuts (%)	-	-	-	-	13	13	-	-
Cassava (%)	-	-	-	-	13	-	-	-
Qat (%)	-	-	-	-	-	25	50	50
Tobacco (%)	-	-	-	-	4	50	-	-
Dairy cattle (%)	46	44	67	83	-	-	-	-
Vegetables (kale, melon, tomatoes) (%)	77	55	44	-	47	63	21	67
Coffee (%)	-	-	22	17	-	-	-	-
Cut flowers (%)	-	-	11	17	-	-	-	-
Bananas (%)	23	11	-	-	-	-	-	-
Av. number of activities per farm	2.3	1.9	2.0	1.7	2.0	2.0	2.0	1.7

Table 12 Dissemination of information from the FFS to non-FFS members within the village and to neighbouring villages (% of farm households responding positive to indicated statements)

	In same village (n=14)	*neighbouring village (n=17)*
FFS is major source of info	86	42
Aware of existence of FFS	100	66
Technologies adopted form FFS	76	32
Information received from FFS	78	51
Willingness to start/join FFS	87	95

Livelihood impacts
With the exception of the health situation, a majority of the farm households observed a positive trend in livelihood aspects (health, soil fertility, water, cash flow, reserves for catastrophes, networks and relations, role of women in decision making, access to markets, food security and diversity sources of income) over the past 3 years (60-75% of the respondents were positive on the identified aspects). The farm households participating in the FFS expressed a general positive contribution of the FFS activities to the livelihood aspects, with only a low score on health aspects.

FFS methodology
The FFS members gave a positive evaluation of all the activities carried out in the FFS (90-100% of households positive). However, only about 75% of the respondents gave a positive rating on commercial activities. Many of the farmers would have preferred more attention to commercial activities than was realised. In two of the FFS, problems with the leadership were encountered and new elections were necessary for a smooth continuation of the activities. More attention needs to be paid to time management, since duration of meetings and long decision-making processes were noted as negative points. All FFS members expressed willingness to continue within the framework of the FFS and wanted to focus on developing commercial, income-generating activities (50% of respondents) and group savings (20%) rather than on research and technology development (15%).

Discussion and Conclusions

The technical learning and innovation processes in FFS showed a positive impact on knowledge, skills and experimentation/innovation capacities of the its members. Adoption of the technologies tested by the farm households is selective, and higher if evaluated positively during experimentation on the central plot. Seven of technologies tested (manure, fertiliser, composting, double digging, tumbukiza, Tithonia and Rhizobium) as well as modified livestock management and feeding practices were adopted by 40-70% of the farmers. As a result, farm households reported higher productivity and financial returns, while soil partial soil nutrient balances showed equal or declining nutrient depletion. Since the impact assessment was conducted only one year after the end of the facilitation period, no information could be gathered about farmers abandoning newly adopted technologies. Another assessment after 2-3 years could provide valuable information about the sustainability of the adoption of the technologies.

The major adaptations made in the approach, compared to the original IPM-FFS (long-term group process, flexible type and frequency of activities, on-farm experimentation in addition to central plot experimentation, no initial grants) appear to be appropriate for addressing soil fertility management in complex smallholder African farming systems. One year after the end of external facilitation, all four schools were still fully up and running. However, the implementation of joint commercial activities was the dominant driving force for sustaining the group process, rather than learning and innovation on soil fertility issues. Although experimentation on the individual farms and the central plot was continued, the FFS activities focused on implementing and initiating commercial activities. In field experiments farmers did not perceive risk of yield loss as a major constraint, while farmers were very risk averse in discussions about experiments involving their livestock. In farming systems with small holding sizes and in areas with a high incidence of crop failure, aspects of risk should receive specific attention in the FFS process.

Given these experiences it is concluded that the potential impacts of FFS extend beyond participatory learning and innovation processes in farm management. FFS can be considered as a stepping stone to establish or strengthen farmers' organisations, linking farm households to markets and empowering rural people. Female and male farmers confidently presenting results of experiments during regular FFS meetings, FFS members sharing experiences and expressing their needs during meetings with policy makers at District level and initiatives starting group commercial activities are striking illustrations. Experiences in this project and elsewhere have shown that essential development actions leading to improved income and livelihood, are only taken up by well-functioning community groups. Therefore, in Africa, where the degree of organisation of rural people has always been low, facilitation of bottom-up farmers' organisation should therefore receive high priority by policy makers, education specialists, and private sector partners.

The viability of FFS engaging in a wide range of activities (innovation and learning, commercial activities, group savings etc.) requires good management skills within the group and calls for a flexible and multi-disciplinary input from service providers. The leadership problems encountered in two FFS due to lack of financial transparency, point to the need for increased attention to leadership and group management aspects. Initial facilitation of FFS is mostly provided by agriculture experts from extension or NGO's, supported by research staff. A wider array of FFS activities also calls for other types of technical input such as marketing, processing, cooperative and micro-finance management etc.

Although learning, experimentation and observation appears to be an endogenous existing process with many farm households in East Africa, the role of outsiders such as facilitators, extension agents, researchers and neighbours are essential to provide the necessary impulses for a dynamic process of innovation that meets the demands of farm household in a quickly changing environment. Based on experiences in this project long-term relationships with research and service providers are necessary to establish an effective farmer-led innovation process in agriculture.

Linkages to markets and inclusion of commercial activities (agriculture or non-agriculture) are essential for the long-term sustainability of FFS. In the permanent learning process envisaged in this approach, cash generation by the FFS to sustain the costs of group activities and service providers is essential. Sufficient attention however needs to be paid that learning and innovation activities remain key elements of the group process. The synergy achieved in the FFS approach consisting of strengthening farmers' organisations, linking farm households to markets, empowerment of rural people and experimental learning is can become an example of a sustainable and effective farmer-led process of innovation in smallholder agriculture in East Africa.

The study indicates a relatively limited diffusion of knowledge to non-FFS farm households. This has been observed elsewhere (Feder et al. 2004a; Tripp et al. 2004; Rola et al. 2002) and therefore raises questions about the role of FFS in rural extension strategies. The results of this pilot project give indication about the cost effectiveness of FFS, in comparison to other approaches. Also the issue of the challenges involved and the necessary conditions for up-scaling the approach to national level cannot be addressed on the basis of this pilot activity. Many FFS initiatives in Africa are being undertaken (such as the one of the FAO Land and Water Division (www.fao.org/ag/agl/agll/farmspi) and several countries such as Kenya, Tanzania and Uganda have included the FFS approach in their national research and extension strategy. Up-scaling of the experiences and the required facilitating conditions are priority issues to be addressed by national policy makers and the international development community.

Acknowledgements
The authors acknowledge with gratitude the enthusiastic participation of all farm household members in the four Farmers Field Schools and the extension staff of the Ministry of Agriculture. We also wish to thank the European Commission and the Dutch Ministry of Agriculture, Nature and Food Quality for financial support.

Literature

Abate, A., and Duveskog, D. 2003. Application of Farmer Field School Approach in Kenya. In Sones, K.R., Duveskog, D., and Minjauw, B. (eds). Farmer Field Schools: The Kenyan Experience. Report of the Kenyan Experience of FFS Stakeholders' Forum. ILRI, Nairobi Kenya.

Bingen, J., 2003. Pesticides, Politics and Pest Mnagaement: Toward a Political Economy of Cotton in Sub Saharan Africa. In: Logan, B.I. and Moseley, W.G. (eds.). African Environment and Development: Rhetoris, Programs, Realities. Ashgate Publishers, Burlington VT. pp. 111-126

Braun, A., Jiggins, J., Röling, N., van den Berg, H., and Snijders, P., 2006. A Global Survey and Review of Farmer Field School Experiences. Report Prepared for the International Livestock Research Institute (ILRI), Endelea, Wageningen, The Netherlands

Braun, A.R., Thiele, G., and Fernandez,M., 2002. Farmer Field Schools and local agricultural research committees: complementary platforms for integrated decision-making in sustainable agriculture. Agricultural Research and Extension, Network Paper No.105, ODI, London, UK.

Bunyatta, D. K., Mureithi, J.G., Onyango, C.A., and Ngesa, F.U., 2005. Farmer Field School Effectiveness for Soil and Crop Management in Kenya. Journal of International Agricultural and Extension Education, Vol. 13 (3): 47-64.

Cantner, U., and Pyka, A., 2001. Classifying Technology Policy from an Evolutionary Perspective. Research Policy 30(5): 759–74.

CIAT, 2006. Integrated soil fertility management in the tropics: TSBF-CIAT's achievements and reflections 2002-2005. CIAT publication No. 350. CIAT/TSBS, Cali, Columbia.

CIP/UPWARD, 2003. Farmer Field Schools: from IPM to platforms for learning and empowerment; users' perspectives with agricultural research and development. Los Baños, The Philippines.

Davis, K, 2006. Farmer Field Schools: A Boon or Bust for Extension in Africa? Journal of International Agricultural and Extension Education 13(1): 91-97.

De Jager, A., Van Keulen, H., Mainah, F., Gachimbi, L.N., Itabari, J.K., Thuranira, E.G., and Karuku, A.M., 2005. Attaining sustainable farm management systems in semi-arid areas in Kenya: few technical options, many policy challenges. International Journal of Agricultural Sustainability 3: 189-205.

FAO/ILRI/KARI, 2003. Farmer Field Schools; The Kenyan experience; Report of the Farmers Field School stakeholders' forum March 27th, 2003. FAO, ILRI, KARI, Nairobi, Kenya.

FAO/FARM, 1998. Farmers Field School on integrated nutrient management: facilitator's manual. FAO/FARM, Bangkok, Thailand.

Feder, G., Murgai, R. and Quizon, J.B., 2004a. Sending farmers back to school: the impact of farmer field schools in Indonesia. Review of Agricultural Economics 26 (1): 45-62.

Feder, G., Murgai, R. and Quizon, J.B., 2004b. The acquisition and diffusion of knowledge: the case of pest management training in farmer field schools, Indonesia. Journal of Agricultural Economics 55(2): 221-243

Friis-Hansen, E., 2005. Agricultural Development among Poor Farmers in Soroti District, Uganda: Impact Assessment of Agricultural Technology, Farmer Empowerment and Changes in Opportunity Structure. Paper presented at Impact Assessment Workshop at CIMMYT, Oct 19-21, 2005, Mexico.

Gallagher, K.D., 2003. Fundamental Elements of a Farmers Field School. LEISA Magazine Vol 19 (1). ILEIA, Leusden, The Netherlands

Hounkonnou, D., Offei, S.K., Röling, N., Tossou, R., Van Huis, A., Struik, P.C., and Wienk, J. (eds.), 2004. Diagnostic studies: a research phase in the Convergence of Sciences Programme. Netherlands Journal of Life Sciences, 52 (3/4) (Special issue).

Hughes, O. and Venema, J.H. (eds.), 2005. Integrated soil, water and nutrient management in semi-arid Zimbabwe. Farmer Field Schools Facilitators' Manual, vol. 1. FAO, Harare, Zimbabwe.

IAC, 2004. Realizing the promise and potential of African agriculture: science and technology strategies for improving agricultural productivity and food security in Africa. Amsterdam: Inter Academy Council, Royal Netherlands Academy of Arts and Sciences, Amsterdam, the Netherlands.

Kim, L., and Nelson, R.R. (eds.), 2000. Technology, Learning, and Innovation, Experiences of Newly Industrializing Economies. Cambridge University Press, New York, USA.

Kirchman, H., 1985. Losses, plant uptake and utilization of manure nitrogen during production cycle. Acta Agriculturae Scandinavia, Supplementum 24.

Kenmore, P.E., 1991. Indonesia's Integrated Pest Management: a model for Asia. FAO Intercountry Programme for Integrated Pest Control in rice in South and Southest Asia. FAO, Rome, Italy.

LEISA Magazine, 2003. Learning with Farmers Field Schools. LEISA Magazine Vol 19 (1). ILEIA, Leusden, The Netherlands

Lekasi, J.K, Tanner, J.C., Kimani, S.K. and Harris, P.J.C., 2001a. Manure management in the Kenya Highlands: Practices and potential. HDRA, Kenilworth, UK.

Lekasi, J.K, Tanner, J.C., Kimani, S.K. and Harris, P.J.C., 2001b. Manuring to sustain smallholder livelihoods in the East African Highlands. HDRA, Kenilworth, UK.

Mancini, F., 2006. Impact of integrated pest management farmer field schools on health, farming systems, the environment, and livelihoods of cotton growers in Southern India. . PhD Thesis Wageningen University. Wageningen, the Netherlands.

Matteson, P.C., Gallagher, K.D. and Kenmore, P.E., 1994. Extension of integrated Pest Management for planthoppers in Asian irrigated rice: empowering the user. In: Denno, R.F. and Perfect, T.J. (Eds.) Ecology and Management of the planthopper. Chapman and Hall, London, UK.

Minjauw, B., Muriuki, H,G., and Romney, D., 2002. Development of Farm Field School methodology for smallholder dairy farmers in Kenya. Paper presented at International learning workshop on farmer field schools: emerging issues and challenges. Yogyakarta, Indonesia October 21-25, 2002.

Mutandwa, E., and Mpangwa, J.F., 2004. An assessment of impact of FFS on IPM dissemination and use: Evidence from smallholder cotton farmers in the lowveld area of Zimbabwe. Journal of Sustainable Development in Africa 6(2).

NARC, 2004. Impacts of the Group FFS Activities on the Organizational Capacities of the Farmers: Evidence from Pakistan. GCP/PRAS/164/EC: Impact Study of IPM in Pakistan. NARC, Islamabad, Pakistan.

Onduru, D.D., Muchena, F., and De Jager, A., 2003. Farmer Field School on nutrient management. LEISA Magazine Vol. 19 (4): 26-27

Place, F., Kariuki, G., Wangila, J., Kristjanson, P., Makauki, A., and Ndbubi,J., 2004. Assessing the factors underlying differences in achievementt of farmer groups: methodological issues and empirical findings form the highlands of Kenya. Agricultural Systems 82: 257-272

Pontius, J., Dilts, R., and Bartlett, A., 2002. From Farmer Field School to community IPM; Ten years of IPM training in Asia. FAO, Rome, Italy.

Praneetvatakul, S.I., and Waibel, H., 2006. Impact assessment of farmer field school using a multi-period panel data model. Paper presented at the 26th conference of the International Association of Agricultural Economists (IAAE), 12-18 August 2006, Brisbane, Australia.

Quizon, J.B., Feder, G. and Murgai, R., 2001. Fiscal sustainability of agricultural extension: The case of the Farmer Field School approach. Journal on International Agricultural and Extension Education 8: 13-24.

Rola, A. C., Jamias, S.B., and Quizon, J.B., 2002. Do FFS graduates retain and share what they learn? An investigation in Iloilo, Philippines. Journal of Agricultural and Extension Education 9(1): 65-75.

Röling, N.G. and Wagemakers, M.A.E., 1998. Facilitating sustainable agriculture: participatory learning and adaptive management in times of environmental uncertainty. Cambridge University Press, UK

Sanchez, P.A., Shepherd, K.D., Soule, M.J., Place, F.M., Buresh, C.G., and Woomer, P.L., 1997. Soil fertility replenishment in Africa: an investment in natural resource capital. In: Buresh, R.J., Sanchez, P.A., Calhoun, F. (eds.), Replenishing soil fertility in Africa. Soil Science Society of America and ICRAF, Special Publication 51, Madison, Wisconsin, USA.

Smaling, E.M.A., Fresco, L.O. and De Jager A., 1996. Classifying, monitoring and improving soil nutrient stocks and flows in African agriculture, Ambio vol.25 (8): 492 – 496.

Tripp, R., Wijeratne, M. and Piyadasa, V.H., 2004. What should we expect from FFS? A Sri Lanka Case study. World Development 33(10): 1705-1720.

UN Millennium Project, 2005a. Investing in Development: A Practical Plan to Achieve the Millennium Development Goals. New York, USA.

UN Millennium Project 2005b. Innovation: Applying Knowledge in Development. Task Force on Science, Technology, and Innovation. New York, USA.

Van Beek, C.L., De Jager, A., Onduru, D.D. and Gachimbi, L.N., 2004. Agricultural, economic and environmental performance of four farmer field schools in Kenya. INMASP Project Report No. 18, Wageningen UR, Wageningen, the Netherlands.

Van de Fliert, E.,1993. Integrated pest management: farmer field schools generate sustainable practices. A case study in Central Java evaluating IPM training. Wageningen Agricultural University Papers (93)3. PUDOC, Wageningen, 304 pp.

Van de Fliert, E. and Braun, A., 2002. Conceptualizing integrative, farmer participatory research for sustainable agriculture: from opportunities to impact. Agriculture and Human Values 19: 25-38.

Van den Berg, H., 2004. IPM-FFS: A synthesis of 25 impact evaluations. Report prepared for the global IPM facility. Wageningen, The Netherlands

Van den Bosch, H., Gitari, J.N., Ogaro, V.N., Gitari, J.N., Maobe, S., Vlaming, J., 1998. Monitoring nutrient flows and economic performance in African farming systems (NUTMON). III. Monitoring nutrient flows and balances in three districts in Kenya. Agriculture, Ecosystems and Environment 71: 65-82.

Vanlauwe, B., Diels, J., Sanginga, N., and Merckx, R., 2002. Integrated Plant Nutrient Management in Sub-Saharan Africa. CABI, Wallingford, UK, 384 pp.

Zake, J., Walaga, C. and De Jager, A., 2005. Bringing farmers together. LEISA Magazine Vol 21 (2): 26-27.

PART 4 Participatory technology, policy and institutional development to address soil fertility degradation in Africa

De Jager, A., 2005.

Participatory technology, policy and institutional development to address soil fertility degradation in Africa.

Land Use Policy 22: 57-66.

ELSEVIER

Land Use Policy 22 (2005) 57–66

Land Use Policy

www.elsevier.com/locate/landusepol

Participatory technology, policy and institutional development to address soil fertility degradation in Africa

A. de Jager*

Wageningen Agricultural University and Research Centre, Agricultural Economics Research Institute (LEI), P.O. Box 29703, 2502 LS Den Haag, The Hague, The Netherlands

Received 6 January 2003; received in revised form 13 May 2003; accepted 27 June 2003

Abstract

At global scale nutrient flows are unbalanced, resulting in huge surpluses in Western Europe versus negative balances in Africa. Existing policy and socio-economic environments in different parts of the world are the major cause of this situation. At lower spatial scales, a much more complex and diverse picture emerges. In Sub-Saharan Africa, different levels and causes of soil fertility decline are found among agro-ecological zones, soil types, farm systems, wealth groups, urban–rural households, cash and food crops, home fields and bush fields.

Technology development has been the traditional response to address nutrient imbalances in general, and soil fertility decline in Africa in particular. Farm households have continued to develop and adapt existing technology to changing situations. National and international research institutions have followed a variety of changing approaches of which the recently developed participatory approaches have yielded some impressive results in isolated cases. These efforts have, however, not led to the necessary massive reversion of the trend in soil fertility decline. The Dutch policies on nutrient use and the Indonesian policy to adopt Integrated Pest Management are two examples, associated with such major trend reversions. This suggests that promoting and supporting participatory technologies have limited impact when no attention is paid to participatory policy development and implementation.

In order to mobilise farm households in a trend reversion, a number of conditions should be met such as stable prices for agricultural outputs, better input/output prices ratios, influence of land users on the research agenda and private-public initiatives focused on smallholders.

This observation calls for the establishment of interactive landusers-science-policy triangles at various scales (local, national and international) in which joint learning and mediating may lead to more informed decision making, more focused design of an agricultural sector policy, implementation of policies by effective institutions, and appropriate technology development and implementation. Interventions need to be reoriented: less technology development, more policy influence and institution building.
© 2004 Elsevier Ltd. All rights reserved.

Keywords: Soil fertility degradation; Policy; Institutional development; Africa

Introduction

Since agriculture is its major economic activity, Sub-Saharan Africa (SSA), more than any other region in the world, relies heavily on its environmental resource base. Studies at the continental scale have shown that this resource base is at risk. Water is becoming an increasingly scarce production factor (FAO, 1996), fertile surface soil is being eroded and soil nutrients are mined (Stoorvogel and Smaling, 1990; Smaling, 1998).

*Tel.: +70-3358341; fax: +70-3615624.
E-mail address: andre.dejager@wur.nl (A. de Jager).

0264-8377/$ - see front matter © 2004 Elsevier Ltd. All rights reserved.
doi:10.1016/j.landusepol.2003.06.002

In the past decade African countries have been confronted with a number of processes affecting the livelihood of the urban and rural populations:

- Increasing poverty combined with fast population growth;
- Urbanisation and migration;
- Evolution to market economies unsupported by environmental policies and regulations;
- Political transition and changing roles of governments;
- Stagnating technological development and limited development of non-agricultural sectors (World Bank, 1996; Pinstrup-Andersen, 2000).

Because of these developments, farm households were forced gradually to transform relatively stable extensive systems into more intensive systems relying on external input and output market forces or move into ecologically more fragile areas. Structural adjustment policies, globalisation of the world market for agricultural products, combined with imperfectly functioning markets and governments within low income countries in Africa, often resulted in deteriorating terms of trade for farm households (Kuyvenhoven et al., 1999; Scoones and Toulmin, 1999; Stiglitz, 2002). In these circumstances, farm households rightly adopt a short time horizon for decision making, resulting in much lower priorities to long-term aspects such as sustainable management of natural resources. In the short and long-term these processes and decisions will affect the livelihood of millions of people in rural and urban areas in SSA.

Much technical research has been conducted on the issues of declining of the natural resource base of agricultural systems (Mokwunye et al., 1996; Braun et al., 1997; Muchena et al., this issue), and scenario studies have shown that there are no real technical barriers to producing sufficient food for all people in SSA in the next 50 years (Gilland, 2002). Many SSA governments, often with assistance of international agencies and donors, have formulated strategies to increase agricultural income, increase cash and food crop output, increase agricultural employment and stimulate development of technologies for sustainable natural resource management. Farmers have not responded to government rhetoric, because effective implementation of these strategies has been lacking. Therefore implementation of these technologies and impact on agricultural production and natural resource management in smallholder agriculture in SSA have been limited.

In this paper, the diversity and complexity of soil fertility degradation in SSA is sketched. The responses by various actors to the problem are described and an analysis is made of why the impacts have been limited. It is argued that creating enabling conditions for smallholder farm households should receive the highest priority in research and development programmes in order to stimulate creative and entrepreneurial processes by the stakeholders to combat soil fertility degradation. Strategies and suggestions to achieve the above mentioned are discussed at the end of this paper.

Diversity in scale and sources of problems

At global scale there are imbalances in nutrient flows. In general, input flows exceed outputs in the 'developed world' in the North (Oenema and Heinen, 1999) and negative balances prevail in SSA (Stoorvogel and Smaling, 1990). These in-balances are the result of global trade flows of primary agricultural products from South to North, and the production and application levels of inorganic fertilisers in the North. Existing policy and socio-economic environments in the North stimulate high levels of fertiliser application and the import of cheap animal feed and concentrates, mainly from 'developing countries'. This results in nutrient surpluses at almost all spatial scales of which the highly intensive dairy farming systems in The Netherlands are an extreme example (Smaling et al., 2002). At the continental scale, negative nutrient balances dominate in SSA, mainly due to low levels of inorganic fertilisers applied and natural processes such as leaching and erosion.

Moving to lower spatial scales, a much more complex and diverse picture emerges. In Sub-Saharan Africa, different levels and causes of soil fertility decline are found among districts, agro-ecological zones, soil types, farm systems, wealth groups, urban-rural households, cash and food crops, home fields and bush fields (Hilhorst and Muchena, 2000; Smaling et al., 2002; Scoones, 2001).

The diversity can be illustrated using results of soil fertility management studies conducted in the past decade in East Africa. Large differences in soil fertility management practices and resulting nutrient flows and balances are observed between agro-ecological zones (Table 1). In the high potential zones of Kenya, intensive farming systems prevail with cash crops (tea, coffee) and milk production in zero-grazing units. Relatively high levels of nutrients are imported in the form of inorganic fertilisers and animal feed, and exported in the form of tea, coffee and milk. Farm balances are highly negative as a result of high estimated losses by leaching, erosion and gaseous losses. High losses are also observed in manure handling in the zero-grazing unit and application of the manure in the napier grass and other crops (Van den Bosch et al., 1998). In the drier zones, much lower levels of imports and exports of nutrients are observed. In an environment of relatively high risks of crop failure due to drought, application of inorganic fertilisers to foodcrops is not an attractive proposition. Less intensive livestock management reduces the possibility of manure application on crops. Slightly negative nutrient balances are observed, but yield levels are low and financial returns of the enterprises are insufficient to sustain livelihoods of the farm families (de Jager et al., 1998). In areas with relatively low population densities, extensive cattle management with grazing in communal land enables nutrient transfers to the areas used for crop cultivation. At farm level, this results in a nearly balanced situation of nutrient flows. However, this situation can only remain stable as long as sufficient common grazing land remains available in the district.

Within agro-ecological zones, large variation may exist between different groups of farm households. In a study in three districts in Kenya (Embu, Kisii and Kakamega), the market orientation of the farm households appeared to be an important factor characterising soil fertility management (Table 2). Market-oriented farm households applied higher levels of inorganic fertilisers and/or imported more feed for livestock, but also lost large quantities of nutrients due to inefficiencies, leaching and erosion. In Nyeri, as in many areas in Kenya, off-farm income largely determines the income levels of farm households (Table 3). No significant differences in import and export of nutrients were observed between groups with incomes below and above the poverty line. In the low-income group however, erosion was significantly higher, resulting in more negative N and K balances. This is probably due to the less favourable location of the farms. (Mainah et al., 2003). In the semi-arid areas, the availability of water, often by simple irrigation systems, determines the land use options and related soil fertility management practices and creates differences in soil fertility management practices and incomes between households with and without irrigation (Table 4). Variable roles of livestock and various types of management create a wide range of soil fertility management options for farm households.

Within rather homogeneous groups of farm households with similar basic resource endowments in one agro-ecological zone, often considerable differences in farm management practices, yields and financial returns are found (Table 5). This is in line with results in European agriculture where it is observed that aspects such as individual management qualities, knowledge, experience, innovativeness, and formal education of the farm household members are important determinants for success. It is this diversity which can be used effectively in research and development activities both in

Table 1
Average farm level N flows in 3 different agro-ecological zones in Kenya and Uganda (average figures for 1997–1998)

	Nyeri (Kenya)	Machakos (Kenya)	Palissa (Uganda)
Zone	High potential	Low/medium potential	Low/medium potential
Soil	Andodols, Nitisols (clay)	Luvisols (loamy-sand)	Ferasols
Rainfall (mm/year)	1200–2000	500–900	800–1200
Population (prs/km^2)	250	100	100
Farming system	Tea, coffee, maize Dairy cattle (zero-grazing)	Maize, beans, sorghum Cattle (corralled at night)	Maize, cotton, beans Cattle (free-ranging)
Market orientation	High	Medium	Low
Off-farm income	High	High	Low
N-balance at farm level			
Mineral fertiliser (kg ha^{-1} yr^{-1})	76	4	2
Organic fertiliser (kg ha^{-1} yr^{-1})	45	6	5
Products out (kg ha^{-1} yr^{-1})	−33	−2	−5
Full balance[a] (kg ha^{-1} yr^{-1})	−185	−55	−3

[a] Including estimated flows such as atmospheric deposition, biological fixation, leaching, gaseous losses and erosion.

Table 2
Farm management, nutrient balances, and economic performance according to market orientation of farms (expressed in % of gross returns for farms in Embu, Kisii and Kakamega) (standard deviations in parentheses; 1995)

	Market orientation		
	<33% ($n=9$)	33–66% ($n=11$)	>66% ($n=6$)
N-balance (kg ha^{-1})	−26[a] (79)	−89 (59)	−106[b] (46)
P-balance (kg ha^{-1})	−2 (11)	5 (15)	6 (20)
K-balance (kg ha^{-1})	32[b] (69)	−12[b] (26)	−68[a] (36)
Net farm income (US$ farm^{-1})	1380 (1080)	1615 (1050)	1455 (1608)
Farm net cash flow (US$ farm^{-1})	182[a] (241)	764 (525)	1236[b] (1624)
Farm income sustainability ratio	0.73 (1.24)	0.56 (0.43)	0.62 (0.35)
Cultivated area (ha)	6.7 (7.9)	4.3 (3.1)	1.7 (0.5)
Tropical livestock units	4.4[b] (1.9)	4.2[b] (3.0)	1.5[a] (0.8)
Zero-grazing unit (1 = yes/2 = no)	2.0[a] (0)	1.5[b] (0.5)	1.4[b] (0.6)
Share of livestock in income (%)	61[a] (22)	63[a] (29)	16[b] (18)
N-inflow fertilisers (IN1 in kg ha^{-1})	9[a] (24)	18[a] (15)	45[b] (41)
N-inflow organics (IN2 in kg ha^{-1})	54 (63)	21 (25)	14 (12)
Labour intensity crops (days ha^{-1})	179 (184)	226 (177)	373 (224)
Labour intensity livestock (days ha^{-1})	71 (51)	48 (17)	91 (104)

Europe (Dutch horticultural study groups) and in Africa (Farmers' field schools, various participatory research approaches; Onduru et al., 2001).

Research response: technology development

Over the past decades, a wide array of technologies to improve the productive capacity of soils in SSA has been developed. Research institutions and development organisations as well as farmers themselves have addressed the observed problems of soil fertility decline, through the development of alternative soil fertility management systems, soil conservation investments or through import of outside resources, such as mineral fertilisers. It is important to distinguish between technologies that:

- Reduce losses of nutrients from the agro-ecosystem, by applying erosion control, restitution of residues, agro-forestry and recycling of household wastes and animal manure.
- Add nutrients to the agro-ecosystem, such as application of inorganic fertilisers and amendments, concentrates for livestock, organic inputs from outside and N-fixation by leguminous species.

Attempts have been made to summarise existing technologies aiming at maintaining and/or improving soil fertility with emphasis on West Africa (Mokwunye et al., 1996) and East and Southern Africa (Braun et al., 1997) respectively. The following categories were distinguished: (i) inorganic fertilisers, (ii) mineral soil amendments, (iii) organic inputs, (iv) improved low-external input systems, (v) soil and water management and conservation and (vi) Integrated Nutrient Management.

Over the years, a number of changes in approaches to technology development have taken place:

- From blanket recommendations to addressing site-specific problems;
- From top-down methods to increased stakeholder participation;
- Taking the social and economic environment of farm households into account;
- Linking technology development to the multiple and diverse livelihood strategies of farm households.

Table 3
Average characteristics of farm households in Nyeri with an income below and above the poverty line (averages for 1997–1998)

Variables	Below poverty line ($n=9$)	Above poverty line ($n=9$)
Total farm area (in ha)	0.87	1.06
Average slope (in %)	20	21
Total tropical livestock units	1.4	2.0
Total nitrogen stock (in $kg\,ha^{-1}$)	11536	12981
Farm nitrogen balance (in $kg\,ha^{-1}\,yr^{-1}$)	−232	−138
Farm phosphorus balance (in $kg\,ha^{-1}\,yr^{-1}$)	−81	−17
Farm potassium balance (in $kg\,ha^{-1}\,yr^{-1}$)	−100	−24
Inorganic fertiliser (N in $kg\,ha^{-1}\,yr^{-1}$)	64	86
Organic fertiliser (N in $kg\,ha^{-1}\,yr^{-1}$)	42	48
Leaching (N in $kg\,ha^{-1}\,yr^{-1}$)	−81	−87
Gaseous losses (N in $kg\,ha^{-1}\,yr^{-1}$)	−67	−71
Erosion (N in $kg\,ha^{-1}\,yr^{-1}$)	−160	−89
Net farm income (in $Ksh\,farm^{-1}\,yr^{-1}$)	50,567	45,485
Off farm income ($Ksh\,farm^{-1}\,yr^{-1}$)	5586	82,440

Table 4
Average characteristics of farm households with irrigation (Matuu) and without (Kionyweni) in the semi-arid areas of Kenya (standard deviations in parentheses)

	Matuu year 1999	Kionyweni year 1999	Kionyweni year 2000
Total farm area (ha)	1.5 (0.7)	2.3 (2.3)	2.3 (2.3)
Total TLU	6.1 (-)	4.9 (-)	4.9 (-)
Net farm income ($Ksh\,farm^{-1}\,yr^{-1} \times 1000$)	172 (-)	5 (-)	57 (-)
Off farm income ($Ksh\,farm^{-1}\,yr^{-1} \times 1000$)	10 (-)	11 (-)	0 (0)
Inorganic fertiliser (N in $kg\,ha^{-1}$)	5 (10)	2 (6)	1 (2)
Organic fertiliser (N in $kg\,ha^{-1}$)	7 (8)	5 (9)	1 (1)
Grazing (N in $kg\,ha^{-1}$)	1 (5)	0 (1)	13 (18)
Atmospheric deposition (N in $kg\,ha^{-1}$)	3 (0)	2 (0)	2 (0)
Biological fixation (N in $kg\,ha^{-1}$)	13 (12)	1 (2)	4 (4)
Crop products (N in $kg\,ha^{-1}$)	−16 (23)	−1 (2)	0 (1)
Crop residues (N in $kg\,ha^{-1}$)	0 (1)	0 (1)	0 (0)
Manure (N in $kg\,ha^{-1}$)	0 (2)	0 (0)	−6 (9)
Leaching (N in $kg\,ha^{-1}$)	−15 (6)	−7 (7)	−7 (10)
Gaseous losses (N in $kg\,ha^{-1}$)	−4 (2)	−2 (4)	−2 (5)
Erosion (N in $kg\,ha^{-1}$)	−1 (1)	−1 (1)	−1 (2)
Human excreta (N in $kg\,ha^{-1}$)	−7 (5)	−5 (6)	−5 (6)
Total N balance ($kg\,ha^{-1}$)	−14 (14)	−6 (15)	−1 (19)
Total N-stock ($kg\,ha^{-1}$)	3016 (703)	1765 (566)	1765 (566)

Table 5
Coefficients of variation for a number characteristics in groups of farm households with comparable resources in 5 semi-arid districts, Kenya (1999–2000)

	Matuu	Kasikeu	Kibwezi	Kionyweni	Kiomo	Kajiado
N-stock	23	98	133	32	17	56
P-stock	79	217	47	38	71	68
K-stock	57	44	32	37	32	53
N-balance	98	155	463	113	176	74
Fertiliser input (IN 1)	210	169	129	247	387	176
Organic input (IN 2)	117	178	184	198	115	283
Net farm income	107	136	356	939	136	330
Off-farm income	186	120	121	158	145	—

These changes in approach have yielded some impressive results at local level in technology development (Reij and Waters-Bayer, 2002) and increased research capacity at farmers' level. They have however, not led to a reversion of the trend in soil fertility decline.

Policy makers' response: caught between conflicting interests

The responses of policy makers to soil degradation problems have been limited, not very well targeted, and implemented with only limited success. This can partly be attributed to the ignorance of this problem at the national policy level (Keeley and Scoones, 2000). The long-term impacts of a gradual process of soil degradation have only recently been recognised at national policy level, mainly due to neglect of their negative environmental and production impacts in national accounts and project calculations. Moreover, policy makers have to combine multiple goals, such as rapid income growth, food security and food price stability and a desirable income distribution. Facilitating sustainable natural resource management is an objective that is currently being included in national policy documents. Policy instruments to achieve this objective include macro-economic policies, public investments, commodity specific policies, price stabilisation policies and public regulation.

In addition, national policies have been largely influenced by international level liberal reforms such as the WTO-negotiations and the structural adjustment programs (SAPs) supported by the World Bank and IMF. In SSA, implementation of these programs at national level have resulted in (i) direct and significant increases in farm-gate prices for agro-chemical inputs (de Jager et al., 1998; Reardon et al., 1997), (ii) very limited increases in farm-gate prices for food products (Koning et al., 1998), (iii) privatisation of input supply resulting in reduced access in marginal areas, and (iv) declining research and extension capacity.

Liberalisation has had limited positive impacts on agricultural development and food security in SSA. Agricultural growth realised was only partly a result of productivity increases, the remainder a result of area expansion, while these policies have contributed to further soil degradation (Koning et al., 1998; Van Meijl and Van Tongeren, 2001). It may be questioned whether the agricultural sector in SSA can develop under free trade conditions, as is currently assumed and implemented.

Hence, it may be concluded that technology development in the area of soil fertility management needs to be closely linked to policy development to ensure large scale impacts. Policy instruments may influence the demographic situation, market conditions, institutional factors, information and available technology, public and community investments in land management and ecological conditions, all of which affect decision making at farm household level, including soil fertility management. Policies should aim at creating conditions for economically sound production of food and cash crops by the domestic agricultural sector. Increased opportunities for better economic performance, in combination with sound institutional structures, are conditions for increased adoption of soil and water conservation practices and reduced soil nutrient mining.

Farmers' response: coping strategies

Farm management decisions are taken at various levels (village, household, individual) and deal with various types of activities (production, food stocks, consumption and marketing). Studies in SSA reveal that farmers' strategies aim at a mixture of food self-sufficiency, profit or cash maximisation, risk aversion and long-term security of livelihood (Haen and Runge-Metzger, 1990; Maatman, 2000). Depending on the prevailing conditions, one or more strategies are dominant. For instance, in agriculturally marginal areas, strategies are described as the economy of survival, comprising decisions with a short-term planning horizon. The fact that a farm household is at the same time a production as well as a consumption unit has an influence on the decision processes (Low, 1986). Conditions in SSA have changed in the past decades due to increasing population density, increased resource degradation, greater integration in the market economy and increased urbanisation. Two distinct responses of smallholder farmers to these developments are observed: (i) development of indigenous technologies and (ii) limited adoption of alternative technologies that often require higher cash expenses.

Indigenous technologies

Farm households have developed different strategies to cope with the variable and changing environments and have increased productivity, income levels and conservation of the national resource base by developing indigenous technologies, such as the use of termite mounds, integration of *Acacia albida* in farming systems, 'zai', valley-bottom cultivation, and composting (Richards, 1985; Reijntjes et al., 1992; Reij et al., 1996).

To some extent the development of low-input ecological technologies can be seen as a defensive reaction of farmers to adverse economic conditions. These technologies are relatively efficient at low productivity levels and are attractive for farmers when prices of outputs are low, prices of input high and infrastructure underdeveloped. In the long-term however they do not suffice to guarantee food security for an increasing population. Integrated with science-based technologies, indigenous technologies can, however, play an important role in addressing the problems of natural resource degradation.

New technologies

Adoption of new technology is determined by the characteristics of the household (education, social status, attitude, social influence, estimated skills, resource endowments), its objectives or strategies together with the characteristics of the technology, such as its relative advantage, its profitability, compatibility, complexity, triability and observability (Rogers, 1983). In addition, external factors, such as infrastructure and geophysical conditions will determine the adoption of specific practices. In the process of technology development and dissemination, little attention has been paid to processes of innovation, adoption-decision behaviour and adaptation of technology to fit local circumstances.

For most farm households in SSA, short-term economic returns are an essential criterion for adoption of technologies. To account for risk, opportunity costs, additional labour costs, a Value Cost Ratio (VCR) of 2 is considered the minimum value for farm households to show interest in adoption of a technology. Various studies have shown that soil fertility improvements in rainfed food crops in SSA, barely meet that condition (Van der Pol, 1993). More recent studies show a similar picture in the semi-arid areas of Kenya where combinations of fertilisers and organic inputs on rainfed maize yielded VCRs in the range of 0.2–1.8 (Table 6; de Jager and van Keulen, 2003). On high value crops that generate high VCRs or sufficient cash, such as vegetables, tea and cotton farmers apply high levels of inorganic fertilisers or organic inputs.

However, in addition to short-term economic profitability, other considerations may influence the decision about adoption of technologies. These include: appropriateness of the technologies for the specific situation of the farm household, time horizon, land tenure arrangements, perception of the problem at farm household level, insufficient technical knowledge, supportive infrastructure, marketing possibilities and market access, social acceptability, price stability of outputs and inputs, degree of participation in policy and technology development.

If technology is appropriate and the socio-economic environment is favourable, farmers adopt and develop conservation practices and sustainable nutrient management practices. In Kitui and Machakos districts of Kenya, farmers adopted 'fanya juu' terraces despite lack of any government support (Pagiola, 1996). In the cotton zones of Mali and Burkina Faso farmers apply productivity enhancing inputs and resource conservation investments due to profitability of the crop and well organised production chain, providing both access to inputs and credit as well as stable markets for the products (Reardon et al., 1997). On the other hand, most measures to combat soil erosion will only pay off in the long-term time and at low discount rates. Since farmers are expected to apply higher discount rates and largely ignore off-site impacts of land degradation, support from society is required to successfully implement these technologies.

Policy-induced changes in farm management practices

A distinction should be made between policies such as fiscal, monetary, trade or price and market policies, that are aiming at influencing the general economic environment in a country, and policies aiming at dealing with a specific issue in a certain sector. Two examples are given where specific policy induced changes have been successful in changing farm management practices.

MINAS in The Netherlands

High inputs of external nutrients by inorganic fertilisers and concentrates feed in combination with

Table 6
Value-cost ratios for soil fertility practices in 3 research clusters in semi-arid areas of Kenya (1999–2000)

	V/C
Treatments maize in Matuu	
Farmers' practice	—
5 ton/ha FYM	−1.43
130 kg/ha DAP + 135 kg/ha CAN	0.80
5 ton/ha FYM + 135 kg/ha CAN	0.35
5 ton/ha FYM + 130 kg/ha DAP + 135 kg/ha CAN	1.04
Treatments maize/cowpeas in Kionyweni	
Farmers' practice	—
5 ton/ha FYM + 42 kg/ha CAN	1.68
20 ton/ha FYM	0.72
40 ton/ha FYM	0.61
Treatments maize Kasikeu	
Farmers' practice	—
100 kg/ha 20/20/0	1.46
200 kg/ha 20/20/0	1.70
20 ton/ha FYM (impact over2 seasons)	0.86
40 ton/ha FYM (impact over 2 seasons)	0.99
50 kg/ha 20/20/0 + 10 ton/ha FYM	1.15
100 kg/ha 20/20/0 + 20 ton/ha FYM	0.53

$V/C = P(O_{T1} - O_{TC})/P(I_{T1} - I_{TC})$.
P = price; O_{T1} = output treatment 1; O_{TC} = output treatment control; I_{T1} = input treatment 1; I_{TC} = input treatment control.
FYM: farm yard manure.
CAN: calcium ammonium nitrate.
DAP: di-ammonium phosphate.

professional farm management made it possible to reach very high levels of agricultural production in The Netherlands. High nutrient inputs also resulted in large nutrient losses and thus adverse effects on groundwater, surface water and the atmosphere. To reduce nutrient emissions from agriculture, the Dutch government has introduced a series of regulations on nutrient use, including:

- a ban on spreading animal manure on agricultural land during the winter period,
- the obligation to cover storage facilities for animal manure,
- compulsory low-emission application of animal manure to land, and
- levies on exceeding the maximum permissible annual nitrogen and phosphorus surplus (INs minus OUTs) for farms.

To effect this EU policy, the MINerals Accounting System (MINAS) was introduced in The Netherlands. The system follows a farmgate approach, i.e., all N and P entering and leaving the farm have to be accounted for. This is the first experience with nutrient budgets as a repressive policy instrument in practice. Within the Dutch context the system has resulted in considerable changes in farm management practices, although not all the specified targets have been met (Ondersteijn et al., 2002).

Farmers' field schools in Asia

After the government of Indonesia was convinced that Integrated Pest Management was much more effective in brown planthopper control in rice than the traditional methods based on chemical control, an active nation-wide policy was implemented. It aimed at the establishment of farmers' field schools to train farmers in the essentials of Integrated Pest Management. At the same time a number of chemicals were banned for use in rice (Röing and Van der Fliert, 1998). It resulted in a major change in pest management practices in the majority of the rice-growing farm households in Indonesia and in major change in the research and development process where researchers, extensionists and farmers are jointly learning and developing technologies. The 'farmers' field school' approach has gradually been expanding to other aspects of the agricultural production process, such as Integrated Nutrient Management and to other countries, both in Asia and in Africa.

These examples show that massive changes in farm management practices can be induced by focused and effectively implemented policies. In both examples, a relatively well-organised and effective public sector was in place. Where this is lacking, as in most countries in Africa, such massive changes are far more difficult to realise.

Creating a favourable entrepreneurial environment

Almost all African countries have issued policy documents addressing the sustainable use of natural resources, but effective implementation and enforcement of polices are all but absent.

Two situations prevent farmers from managing natural resources effectively and sustainably: when general public policies bias decisions against their optimal use and when there is a disparity between private and social costs. Both situations apply to soil fertility degradation issues in most African countries.

With respect to the first point, the most important conditions that have to be met in Africa to mobilise farm households to manage their soils in a more sustainable way:

Stable and reasonable prices for agricultural products

Farm households in Africa are confronted with relatively low prices for staple food crops, with large variability among years depending on the weather (rainfall), national price or trade policies and international market developments. Cash crops such as vegetables and tea fetch higher prices, which induces farmers to adopt better soil fertility management practices.

Increase output/input price ratios

Imperfectly functioning markets in Africa make it difficult for farmers to optimise soil fertility management. Fertiliser prices are two to seven times higher for farmers in remote areas in Africa than for their counterparts in Europe (Sanchez, 2002). This requires general investments in infrastructure such as transport and roads, but also addressing sensitive issues as corruption.

Sufficient employment alternatives outside primary agricultural production

The absence of sufficient employment opportunities keeps many people within the agricultural sector. Because of insecurity, even persons with employment in industry or services keep a piece of land in the rural area. This hampers the development of an efficient agricultural sector, that can compete on the regional and international markets.

With respect to the second point, specific and focused policies have to be implemented by the public sector among others.

Increasing the efficiency of research and extension institutions

Reorganisations should lead to situations where users have more decision power over the research and extension funds and the research agenda. This requires among others a smooth and intensive collaboration with extension services and NGO's, beyond the time horizon of specific projects or activities.

Stimulating public–private partnerships and initiatives focused on smallholders examples of successful public–private partnerships

- The Sustainable Community-Oriented Development Programme (SCODP) started a scheme in 1995 to supply inorganic fertilisers in small 100 and 200 g bags in Western Kenya. Demands for the minipacks grew and the project expanded through Kenya to include other inputs and integrate research, extension and marketing. In cooperation with seed, fertiliser and crop protection product suppliers new methods of mini-pack distribution and promotion among small farmers are being developed (Okello and Seward, 2000).
- At Moi University (Kenya) a pilot product was designed to ameliorate low fertility patches in smallholders' fields using phosphate rock. The product was tested on-farm and provided to five local NGO's and one partner in the private sector for evaluation. Thereafter the product was distributed free of charge to 42 area retailers to establish potential product demand at various prices. Several retailers are now marketing the product and one NGO has established a second assembly facility (Woomer et al., 2002).

Long-term land use rights for farmers

Any form of longer-term security is an essential condition for farm households to invest in land improvements. Especially in situations where multiple land uses are possible, such as in peri-urban areas, specific policies and regulations are required to provide such long-term land use rights.

Focussed small-scale credit facilities for agricultural diversification

To increase the financial returns at the farm household level and thus improve the conditions for long-term investments in land, diversification of agricultural activities needs to be promoted. However, for setting up more profitable agricultural enterprises, such as vegetable production and processing, milk production and processing and flower production, investments are required, while credit facilities for small-scale farmers are absent or too costly.

Supporting establishment of farmers and community organisations

Well functioning farmers or community based organisations create more option for small-scale entrepreneurs, for example, joint procurement of agricultural inputs, learning, development and exchange of technical information (such as in farmers' field schools), marketing linkages to private enterprises (flower and vegetable exports in East Africa).

A wide array of technical options has been developed and proven to be effective at the research or project level. The absence of a reversion of the trend in soil fertility decline in Africa must therefore be attributed to the lack of a conducive environment for farm households to implement the available technologies. This conclusion leads to calls for initiatives aiming at the establishment of interactive land-user-science-policy triangles at various scales (local, national and international). In these, joint learning and mediating may lead to more informed decision making more focused design of an agricultural sector policy, implementation of policies by effective institutions, and appropriate technology development and implementation. Interventions need to be reoriented: less technology development, more policy influence, and institution building. The fact that a wide array of literature on participatory processes at farm and extension level is available, but hardly any documented, successful experiences are published on methodologies to engage policy makers actively in agricultural development processes is illustrative for this point. It is advocated that projects and interventions should focus on the establishment of agricultural stakeholder platforms at various levels to prioritise problems, to formulate and monitor implementation of policies, to facilitate effective information and communication flows and to reorganise research and development processes. In these, key roles would be played by community based organisations, farmers' field schools, etc. in reaching decisions on issues such as research agendas and budgets.

Acknowledgements

The author would like to thank the two anonymous reviewers for their valuable comments and suggestions to an earlier version of this paper.

References

Braun, A.R., Smaling, E.M.A., Muchugu, E.I., Shepherd, K.D., Corbett, J.D., 1997. Maintenance and improvement of soil productivity in the highlands of Ethiopia, Kenya, Madagascar and Uganda; an inventory of spatial and non-spatial survey and research data on natural resources and land productivity. African Highland Initiative, Technical Report Series no. 6, ICRAF, Nairobi, Kenya.

de Jager, A., Van Keulen, H., 2003. Assessment and monitoring of nutrient flows and stocks and development of appropriate nutrient management strategies for ASAL, Kenya (NUTSAL); report on 11th backstopping mission, NUTSAL mission reports.

de Jager, A., Kariuki, F.M., Matiri, M., Odendo and Wanyama, J.M., 1998. Monitoring nutrient flows and economic performance in African farming systems (NUTMON). IV. Monitoring of farm economic performance in three districts in Kenya. Agriculture, Ecosystems and Environment 71, 81–92.

FAO, 1996. World food summit, Technical background document 7, Food production: the critical role of water, Rome, Italy.

Gilland, B., 2002. World population and food supply; can food production keep pace with population growth in the next half century? Food Policy 27, 47–63.

Haen de, H., Runge-Metzger, A., 1990. Farm households in the process of development as partners in project work'. In: Peasant Household Systems, Proceedings of an international workshop, Feldafing.

Hilhorst, T., Muchena, F.M. (Eds.), 2000. Nutrients on the Move-Soil Fertility Dynamics in African Farming Systems. International Institute for Environment and Development, London.

Keeley, J., Scoones, I., 2000. Global science, global policy: local to global policy processes for soils management in Africa. IDS Working Paper, no. 115, IDS, Brighton, UK.

Koning, N., Heerink, N., Kauffman, S., 1998. Integrated soil improvement and agricultural development in West Africa: why current policy approaches fail. Wageningen Economic Papers 9-98.

Kuyvenhoven, A., Heerink, N., Ruben, R., 1999. Economic policy in support of soil fertility: which interventions after structural adjustment? In: Smaling, E.M.A., Oenema, O., Fresco, L.O. (Eds.), Nutrient Disequilibria in Agroecosystems Concepts and Case studies. CAB International, Wallingford, UK, pp. 119–140.

Low, A., 1986. On-farm research and household economics. In: Moock, Joyce L. (Ed.), Understanding African Rural Households and Farming Systems. Westview Press, London.

Maatman, A., 2000. Si le fleuve se tord, que le crocodile se torde; une analyse des systèmes agraires de la région Nord-Ouest du Burkina Faso à l'aide des modèles de programmation mathématique. PhD thesis, Centre for Development Studies, University of Groningen, Groningen, The Netherlands.

Mainah, F.W., Van Keulen, H., de Jager, A., 2003. Assessment and monitoring nutrient flows and stocks to determine appropriate nutrient management strategies in the ASAL's: a NUTMON approach. NUTSAL internal working paper, Wageningen/Nairobi.

Mokwunye, A.U., de Jager, A., Smaling, E.M.A., 1996. Restoring and maintaining the productivity of West African soils: key to sustainable development. IFDC.

Muchena, F.N., Onduru, D.D., Gachini, G.N., de Jager, A. Turning the tides of soil degradation in Africa: capturing the reality and exploring opportunities. Land Use Policy, doi:10.1016/j.landusepol.2003.07.001.

Oenema, O., Heinen, M., 1999. Uncertainties in nutrient budgets due to biases and errors. In: Smaling, E.M.A., Oenema, O., Fresco, L.O. (Eds.), Nutrient Disequilibria in Agroecosystems Concepts and Case studies. CAB International, Wallingford, UK, pp. 75–97.

Okello, D., Seward, P., 2000. Fertilizer mini-packs in Kenya. Fertilizers and Agriculture, March 2000, International Fertilizer Industry Association.

Ondersteijn, C.J.M., Beldman, A.C.G., Daatselaar, C.H.G., Giesen, G.W.J., Huirne, R.B.M., 2002. The Dutch mineral accounting system and the European nitrate directive: implications for N and P management and farm performance. Agriculture, Ecosystems and Environment 92, 283–296.

Onduru, D., de Jager, A., Gachini, G., Diop, J.M., 2001. Exploring new pathways for innovative soil fertility management in Kenya. Managing Africa's Soils No.25, IIED, UK, London.

Pagiola, S., 1996. Price policy and returns to soil conservation in semi-arid Kenya. Environmental and Resource Economics 8, 255–271.

Pinstrup-Andersen, P., 2000. Food policy research for developing countries: emerging issues and unfinished business. Food Policy 20, 125–141.

Reardon, T., Kelly, V., Crawford, E., Diagana, B., Dione, J., Savadogo, K., Broughton, D., 1997. Promoting sustainable intensification and productivity growth in Sahel agriculture after macroeconomic policy reform. Food Policy 22, 317–327.

Reij, C., Waters-Bayer, A. (Eds.), 2002. Farmer Innovation in Africa: A Source of Inspiration for Agricultural Development. Earthscan, London, UK.

Reij, C., Scoones, I., Toulmin, C., 1996. Sustaining the Soil; Indigenous Soil and Water Conservation in Africa. Earthscan, London, UK.

Reijntjes, C., Haverkort, B., Waters-Bayers, A., 1992. Farming for the Future: An Introduction to Low-External-Input and Sustainable. Leusden, The Netherlands.

Richards, P., 1985. Indigenous Agricultural Revolution: Ecology and Food Production in West Africa. Hutchinson, London.

Rogers, E.M., 1983. Communication of Innovations. Free Press, New York.
Röling, N.G, Van der Fliert, E., 1998. Introducing integrated pest management in rice in Indonesia: a pioneering attempt to facilitate large-scale change. In: Röling, N.G., Wagemakers, M.A.E. (Eds.), Facilitating Sustainable Agriculture; Participatory Learning and Adaptive Management in Times of Environmental Uncertainty. University Press, Cambridge.
Sanchez, P.A., 2002. Soil fertility and hunger in Africa. Science. 295, 2019–2020.
Scoones, I., 2001. Dynamics and Diversity: Soil Fertility and Farming Livelihoods in Africa: Case Studies from Ethiopia, Mali and Zimbabwe. Earthscan, London, UK.
Scoones, I., Toulmin, C., 1999. Policies for soil fertility in Africa. A report prepared for the Department of International Development, Institute of Development Studies and International Institute for Environment, London, UK.
Smaling, E.M.A. (Ed.) (1998). Nutrient flows and balances as indicators of productivity and sustainability in sub-Saharan African agro-ecosystems. Agriculture, Ecosystems and Environments (Special Issue) 71, 1–283.
Smaling, E.M.A., Stoorvogel, J.J., de Jager, A., 2002. Decision making on integrated nutrient management through the eyes of the scientist, the land-user and the policy maker. In: Van Lauwe, B., Diels, J., Sanginga, N., Merckx, R. (Eds.), Integrated Plant Nutrient Management in Sub-Saharan Africa: from Concept to Practice. CAB International, Wallingford, UK.
Stiglitz, J., 2002. Globalization and its Discontents. Norton & Company, New York.
Stoorvogel, J.J, Smaling, E.M.A., 1990. Assessment of soil nutrient depletion in sub-Saharan Africa, 1983–2000. Report 28, DLO Winand Staring Centre for Integrated Land, Soil and Water Research (SC-DLO), Wageningen, The Netherlands.
Van der Pol, F., 1993. Analysis and evaluation of options for sustainable agriculture, with special reference to southern Mali. In: van Reuler, H., Prins, W.H. (Eds.), The Role of Plant Nutrients for Sustainable Food Crop Production in Sub Saharan Africa. VKP, Leidschendam.
Van den Bosch, H., Gitari, J.N., Ogaro, V.N., Maobe, S., Vlaming, J., 1998. Monitoring nutrient flows and economic performance in African farming systems (NUTMON) I. Monitoring nutrient flows and balances in three districts in Kenya. Agriculture, Ecosystems and Environment 71, 81–92.
Van Meijl, J.C.M., Van Tongeren, F.W., 2001. Multilateral trade liberalisation and developing countries: A North-South perspective on agriculture and processing sectors. Report 6.01.07, Agricultural Economics Research Institute (LEI), The Hague, The Netherlands.
Woomer, P.L., Mukhwana, E.J., Lynam, J.K., 2002. On-farm research and operational strategies in soil fertility management. In: Van lauwe, B., Diels, J., Sanginga, N., Merckx, R. (Eds.), Integrated Plant Nutrient Management in Sub-Saharan Africa: From Concept to Practice. CABI publishing, UK.
World Bank, 1996. Toward Environmentally Sustainable Development in Sub-Saharan Africa: a World Bank agenda. Development in practice series, Washington DC.

PART 5 Discussion and concluding remarks

PART 5 Discussion and concluding remarks

Introduction

In this part, experiences of applications of the NUTMON approach in East Africa over the years are presented, followed by on overview of observed limitations and critical remarks made by various users. A comparison is made to other related approaches used in East Africa addressing soil fertility. The most recent developments of the NUTMON approach in a revised tool, Monitoring for Quality Improvement (MONQI), and the expected future developments are presented. The role of NUTMON in participatory learning-based approaches in general and in Farmer Field Schools in particular is discussed, culminating in a view on the required development of effective innovation systems in smallholder agriculture and how this can contribute to a sustainable improvement of rural livelihoods in East Africa.

NUTMON and its application in retrospect and future developments

The NUTMON approach in practice

Experiences with the initial version of NUTMON were in general positive (Part 2, Chapter 3 and Part 3, Chapter 4). The research team observed that:

- NUTMON provides an integrative, holistic and quantitative picture of farm management practices and their impacts on nutrient flows and financial performance;
- Incorporation of existing scientific insights enables estimation of complete soil nutrient balances, including difficult to quantify flows such as leaching, gaseous losses and erosion, without time- and resources-consuming data collection and experimentation;
- Transparent quantification of flows allows differentiation between hard data and estimates as the basis for estimation of both, partial and full balances;
- Quantitative diagnosis of farm management practices, nutrient balances and financial performance provides essential information on the impact of current farming practices and on the variation among farms and activities within the farm.

On the other hand, the team also identified limitations and observed that:

- Balances of the (macro-)nutrients N, P and K represent partial indicators of sustainability, since they are not related to nutrient stocks and other essential nutrients and soil organic matter are not taken into account;
- A ‘static’ tool such as NUTMON provides only a snapshot of the actual situation; the absence of dynamic simulation makes it difficult to gain insight in long-term effects of farm management practices on soil fertility and productivity;
- Serious limitations exist in the use of transfer functions to estimate ‘hard-to-quantify’ flows resulting in doubts about the accuracy of the calculated balances;
- Collecting some of the financial data (such as off-farm income) is difficult;
- The process of data collection and data processing is time-consuming for both farmers and researchers.

After a number of years of implementation, the farmers and the research team positively evaluated the role of NUTMON in participatory innovation processes (Part 3, Chapters 5, 6, 7 and 8). The mix of a qualitative and quantitative diagnostic approach facilitated interactions between researchers, extension staff and farmers. However, despite the improvements in the software and the lower frequency of data collection at farm level, the whole process of application of the NUTMON tool was still considered time-consuming both for farmers and researchers. Also the earlier mentioned limitations of the model in terms of the accuracy of the estimated 'hard-to-quantify' flows and the dynamic aspects of nutrient flows and stocks in relation to crop yields were felt as constraints for model application.

In the period 2000–2004, the NUTMON tool received ample attention, especially from researchers in Asia and Africa. It is not possible to present a complete overview of the extent of distribution and use of the NUTMON tool, since the software and manual were distributed free of charge and could be downloaded from the website. Numerous applications of the NUTMON tool in soil fertility-related studies have been reported (e.g. Kanté, 2001, Saidou et al., 2003, Surendran et al., 2005; Abegaz, 2005; Onongwa and Fryer, 2006; Haileslassie et al., 2006; Isabirye et al., 2007). Some even claim that NUTMON is currently the most frequently used integrated approach in the context of research on soil fertility and natural resources management across Africa (Schlecht and Hiernaux, 2004).

The standardised survey instrument of NUTMON is highly valued, since it provides detailed information on actual farm management practices in various farming systems and allows easy comparison of various case studies. This feature of NUTMON has not yet been fully explored. The NUTMON research team currently has a combined database of over 500 farm households in various farming systems in Africa and Asia that has been used as a source for a study on the relative importance of non-farm activities in the various farming systems (Kuiper et al., in press). Another example is the integration of NUTMON data in the trade-off analysis model (www.tradeoffs.nl) that is based on spatially-explicit econometric simulation models linked to spatially-referenced bio-physical simulation models to simulate land use and input use decisions and their impact on e.g. environment, poverty, human health, and food security (Stoorvogel et al., 2004; Stoorvogel et al., 2005).

Limitations and criticism of the NUTMON approach

Over the years, the NUTMON approach and the toolbox have attracted much interest and attention, they have been widely applied by research teams in Africa and Asia, but have been subject to substantial criticism as well. Many of the criticisms deal with aspects of the approach and the toolbox that had already been recognised as problematic by the NUTMON research team as discussed earlier.

Nutrient balances as sustainability indicator

A general and fundamental point of discussion, not directly related to NUTMON as such, is the use of soil/farm nutrient balances in the policy debate and as diagnostic indicators for soil fertility, soil productivity and sustainability. Nutrient balances have been shown to be powerful indicators at policy level, basically because of their diagnostic simplicity: they provide a snapshot of soil nutrient depletion at various system levels. The impact of the earlier mentioned study of Stoorvogel and Smaling in 1990 on the policy debate and research priorities in SSA has been substantial. The major criticisms from the research community were that nutrient balances:

- provide only a snapshot;
- at higher scales are often derived from extrapolations from a limited number of local-specific data;
- tend to ignore the underlying diversity, heterogeneity and complexity of the farming systems and
- do not take into account the many socio-economic and institutional factors (co-)determining farmers' decision making (Scoones and Toulmin, 1998; Smaling and Dixon, 2006).

However, there appears to be a consensus that nutrient balances at higher scales can play an important role in policy debate and dialogue, provided they are used with caution. This view is supported by the experiences in the projects with NUTMON described in this thesis.

At all scales, nutrient balances are useful and appropriate indicators to quantify the extent of the problem of nutrient depletion, but they have been less successful in support of identification of solutions and assessing the impact of interventions and innovations (Stoorvogel, 2007). Assessing the impacts of technological innovations at farm and field scale on nutrient balances requires more insight in the interactions between various nutrient flows, soil organic matter contents, nutrient pools, etc. The static nature of nutrient balances has also led to misuse by extrapolating in time through accumulation of calculated nutrient balances over a number of years. Such a method easily leads to erroneous results when not taking into account the dynamic character of soil nutrient flows and stocks and the many feedbacks in the system (Stoorvogel, 2007). Also estimation of the costs of soil nutrient depletion through multiplying (negative) nutrient balances with the price of the nutrients in mineral fertilizer is debatable. Others are very doubtful about the use of nutrient balances as an appropriate analytical tool for long-term sustainability assessment, since it is difficult to link nutrient losses unequivocally to stocks of nutrients in the system (Tittonell et al., 2006).

<u>'Hard-to-quantify' soil nutrient flows</u>

The NUTMON model has been seriously criticized on the use of transfer functions to arrive at comprehensive soil nutrient balances. The calculation methods to determine erosion, leaching and denitrification in NUTMON in farm and field level studies according to Faerge and Magid (2004):

- do not take into account redistribution of nutrients due to erosion;
- lack specification of the net mineralization rate of N, crucial in the transfer functions for leaching and denitrification;
- lack validation of transfer functions in applications of NUTMON in various agro-ecological zones.

They conclude that the calculated negative full nutrient balances may often be exaggerated. Especially in low input (which often are also low output) systems, where the soil nutrient flows estimated on the basis of transfer functions comprise the major flows, the calculated nutrient balances have a high degree of uncertainty (Kanté, 2001; De Ridder et al., 2004). Validation and sensitivity analyses of calculated soil nutrient balances are therefore important steps (Ramisch, 1999) in applying NUTMON-type approaches for calculating nutrient balances. However, in general, the NUTMON approach is applied without (even attempts at) proper verification of the validity of the transfer functions for the specific area. The NUTMON team has made some attempts at validating the leaching and erosion transfer functions. For instance, in the VARINUTS project in Kenya, field measurements of leaching were conducted, showing that on average in NUTMON leaching losses were over-estimated by 43% (VARINUTS, 2000). In the NUTSAL project, serious considerations were given to validating soil erosion (N, P, K), leaching (N, K), denitrification (N) and losses from animal manure (N) for the specific semi-arid environment. Field experiments could be carried out only for leaching, but no results were achieved due to lack of rainfall in the measurement period. For erosion, no validation experiments were conducted in the various applications of NUTMON by the team, but given the fact that no redistribution is taken into account, it may be expected that erosion losses are over-estimated by the transfer functions in NUTMON. A sensitivity analysis of the calculated nutrient was conducted in the VARINUTS project, improving their interpretation.

<u>Full balances versus partial balances</u>

Appropriate interpretation of soil nutrient flows requires estimation of full balances, that include estimates of losses such as leaching and erosion, which are major sources of nutrient depletion in many farming systems. It is appreciated that the current transfer functions may lead to over-estimation of the losses and that further experimental and analytical work is needed to derive more accurate transfer functions for different agro-ecological zones. However, experience has learned that this is resource–consuming, and moreover, dramatically increases the data demand. It is therefore suggested to maintain relatively simple transfer functions within the model, but use them with caution within the ranges of circumstances for which the functions have been calibrated (soil characteristics, rainfall, etc.) and apply sensitivity analyses to the resulting nutrient balances. Especially for the hard-to-quantify flows it is recommended to present probability ranges rather than single values. If, for instance, erosion and leaching appear to be major sources of nutrient losses and hence, there is a need for further quantification, more focused and data-demanding models should be used for more accurate estimates of these flows.

Given the problems associated with the use of comprehensive balances, various authors advocate use of partial balances (Bekunda and Manzi, 2003; Esilaba et al., 2005; Wijnhoud, 2007). Depending on the method of data collection for the easy-to-quantify flows (IN1, IN2, OUT1 and OUT2; Fig. 2, Part 2, Chapter 3) in general, the accuracy of the partial balances will be higher than that of the comprehensive balances. Wijnhoud (2007) states that a more accurate partial budget may be easier to interpret than a complete budget that suggests unwarranted accuracy. On the other hand, partial nutrient balances often suggest a complete picture of nutrient flows with the associated risk of misinterpretation. For instance, in a study in eastern Uganda, based on analysis of partial nutrient balances, it was concluded that harvesting crops for food and the surplus for sale are the most important sources of nutrient mining in the crop production system (Esilaba et al., 2005). In contrast, estimates of comprehensive balances with NUTMON in a comparable area, suggests that in addition to export in crop products, leaching is a major source of nutrient mining (Part 3, Chapter 6).

Scales
As stated in this thesis, system delineation is important in the interpretation of nutrient balances. The different approaches at different hierarchical scales when calculating nutrient balances and also other sustainability indicators, have been spelled out in detail in various studies (De Ridder, 1997; Roy et al, 2003). Interpretation of results at a specific scale, however, remains tricky. Within-farm variation is often high (Tittonell et al., 2005), hampering proper diagnosis, without knowing the details of this within-farm variation. In case of grazing communal lands positive balances at farm level may exist at the expense of negative balances in the communal land (De Ridder, 1997; Part 3, Chapter 6).

Time-consuming implementation
Despite the improvements in the software over time, the team encountered various constraints in actual field implementation of the NUTMON approach. A comprehensive description of current farm management practices requires a systematic approach in data collection, generates relatively large amounts of data that need to be entered and managed, and requires detailed checks of data on errors and consistency. This calls for dedicated and trained field staff with a thorough knowledge of the farming systems in the area and an interest in 'getting the figures right'. In most of the projects where NUTMON was applied, the required capacity for these activities has been underestimated and the resulting length of the process of generating outputs limited timely and optimal use in the participative diagnostic process with farmers. Adequate specific training for staff is required to address this problem, as well as more attention for the user-friendliness of the software. In fact this implies that specific staff should be available for debugging, error management and improvement of the software

Accuracy of data
Apart from the inventory data that can be observed by enumerators (land area, number of livestock, type of house, etc.) and flows calculated through transfer functions, most of the collected flow data (inputs, outputs, internal flows) are based on farmers' recall. Experience learns that, depending on the period of recall and the relation of the enumerator with the farm household, the accuracy of these data is highly variable, especially with respect to crop yields and labour inputs. This can be addressed by reducing the period of recall (increasing monitoring frequency), conducting sample measurements (yield measurements, labour time recording) or cross-checking with other data sources (records of tea delivered by farmers to

the factory). On the other hand, experience also shows that over time the quality of data recalled by farm household members increases, through the process of learning to observe and keep records and the increased insight in the value and benefits of keeping records.

NUTMON in relation to other approaches

At the start of the NUTMON projects a comparison was made with other approaches and it was concluded: 'that the majority of the approaches encompass agronomic plot and farm level studies. Only in a few cases are economic issues included and sociological aspects are virtually absent. No concrete examples of up-scaling plot and farm field level studies to higher scales have been presented. Most of the methodologies make use of a mix of primary and secondary data to calculate either full or partial balances (not all the nutrient flows taken into account). Apart from the macronutrients N, P, and K, some approaches include also Ca, Mg and C in the balance studies. None of the field level study approaches resulted into concrete policy level recommendations. As compared to the others, NUTMON seems the most comprehensive.' (Part 2, Chapter 2).

Ten years later, the principles of the NUTMON approach have remained the same. NUTMON provides a structured framework for data management that forces systematic quantitative recording of essential farm management and livelihood aspects of farm households. Again now, a comparison is made to other approaches addressing soil fertility. The overview of models is far from comprehensive, and is limited to approaches related to NUTMON and with applications in East Africa.

<u>Diagnostic and monitoring tools</u>
NUTMON complements other more qualitative participatory diagnostic tools. One of these approaches, widely used in eastern Africa is Participatory Learning and Action Research (PLAR; Defoer and Budelman, 2000). Compared to this approach, NUTMON includes estimates of hard-to-quantify flows of nutrients and a financial analysis (crucial for adoption decisions by farmers). Often, a combination of elements from NUTMON and from PLAR is used in the diagnostic activities. For instance, in the NUTSAL project, soil nutrient flow maps, as well as wealth ranking by farm households, components of the PLAR approach, were used (Part 3, Chapter 7). On the other hand, the combination of visualised qualitative nutrient flow diagrams (PLAR) and the quantified nutrient flow and financial performance indicators (NUTMON) proved to be highly effective in a participative process of observation, experimentation and learning (Part 3, Chapters 5, 7 and 8).
NUTMON focuses on the farm household and generates nutrient flows and balances at micro-scale. As stated earlier, up-scaling soil nutrient flows from micro-scale to higher scales is still problematic, but is essential to the policy debate. To generate insight in soil nutrient flows and balances at meso- and macro-scale, other approaches and models have been developed over time using a wide variety of data sources and land use maps (FAO, 2003). Methods have also been developed to carry out soil nutrient audits at national scale (Sheldrick et al., 2002). Micro-scale data are often necessary to verify soil nutrient balances at higher scales, as well for providing information on the diversity within the meso- and macro-scales.

<u>Dynamic simulation approaches</u>
NUTMON differs considerably from other types of models such as simulation and decision rules models (Schlecht and Hiernaux, 2004). Dynamic simulation models offer opportunities for integrated analyses of different options available to smallholder farmers to improve the productivity of their land, while considering the spatial heterogeneity of their farms, the long-term impact of their operational and strategic management decisions, anticipated changes in the biophysical and socio-economic conditions, and monitoring multiple indicators of sustainability at different scales (Tittonell et al., 2007). A number of modelling approaches

have been used for designing sustainable management systems for African smallholders such as the dynamic soil C model ROTHC (Coleman and Jenkinson, 1995), the CERES-maize crop growth model (Jagtap et al.,1999) and several applications of the APSIM crop growth model (Carberry et al., 1996; Keating et al., 2003). A more comprehensive decision rule model has been developed by Struif Bontkes (1999), that enables simulation of the dynamics of farming systems at farm and regional scale, allows tests of technologies, management options and policies.

Linking monitoring and simulation approaches

Modelling for long-term analysis of farming strategies by smallholders, with emphasis on livelihoods, requires simple approaches to avoid being overwhelmed by detail, but that are sensitive enough to capture the spatial and temporal variability of the systems, and the impact of proposed technologies for improvement (Giller et al., 2006). So far, linking the static NUTMON approach to such dynamic but simple simulation models has not been very successful, despite the need felt by many researchers (and policy makers) to develop tools for a more integrated long-term analysis and for evaluation of alternative management practices and policy options. The integration of NUTMON in the trade-off analysis model, however, is a major step in this direction. In that approach use is made of actual farm management data, biophysical and economic aspects are combined and a link to GIS analysis is possible, specifically important for communication of results at the policy level. On the other hand, the model appears as yet too complex for wide application beyond the research community. Stoorvogel (2007) has suggested another approach, with add-ons to the NUTMON model to integrate some more dynamic aspects: a nitrogen balance model and a soil organic matter model. In order to translate nutrient balances into more interesting outcomes for farmers and policy makers such as yield loss and monetary values, it has been suggested to link nutrient balance studies to simple soil fertility/crop production models such as the quantitative evaluation of the fertility of tropical soils or QUEFTS (Janssen et al., 1990). The integrated analytical framework NUANCES offers another opportunity for linking. NUANCES is being developed for embedding analyses of the potential for different soil improving technologies in the context of farm household strategies, through linking of simple summary models representing the various components of the farming systems (Giller et al., 2006) This framework includes, among others, a farm-scale resource management simulator (FARMSIM; Tittonell et al., 2007), aiming at analysing trade-offs between various environmental and economic objectives in the context of farming systems, focusing on strategic decision-making. Other options are to make use of decision-support systems and scenario studies. Also in this case there is often a trade-off between simplicity and comprehensiveness of approaches and models.

Farm-scale bio-economic models

In addition, various farm-scale bio-economic models have been developed, mostly multiple-goal linear programming models, to assess the bio-economic sustainability of farming systems (Hengsdijk and Kruseman, 1992). However, application of the dynamic models has so far been limited, mainly due to the extensive data requirements and the need for calibration of many functions against farming system dynamics.

Prototyping

A different approach is demonstrating packages of proven technologies at field, farm or village level. An example applied in East Africa is the Sasakawa-Global 2000 project that promoted a package of improved seeds, fertilisers and improved crop and land management practices at field level. A more recent example is the Millennium Villages Project (12 villages in SSA) implemented by the Earth Institute in Colombia, that offers an integrated package of interventions in agriculture, health and nutrition, infrastructure, energy, education and training to support villages to get out of poverty. Characteristics of this approach are attempts to attain rapidly impact with a relative big technology and capital push. The approach has been seriously criticized on points such as being of a top-down nature with little choice being left to the beneficiaries in devising solutions embedded in local environmental, socio-economic and cultural realities, excessive reliance on outside assistance, limited sense of ownership, insufficiently taking into account the need for institutional development (markets, storage, processing, transport, etc) (Cabral et al., 2006; Howard et al., 2003). NUTMON and the participatory innovation process differ fundamentally from this approach, since they take existing knowledge and management practices as point of departure and focus on learning, capacity building and developing technological innovations, embedded in local circumstances and empowering people through new social/institutional arrangements.

From NUTMON to MONQI

A new version of the tool was created in response to the need in the research community to expand its application outside the area of soil fertility. Projects in Asia aiming at monitoring use of pesticides in farming systems had already started using an adapted version of the NUTMON toolbox and various requests were received to monitor changes in rural farm household livelihoods following a disaster (tsunami in Aceh) or as a result of project activities in a specific area. In 2005 the research team decided to respond to these developments and started to build a new tool, largely based on the principles of the NUTMON toolbox, but with a much wider scope than nutrient flows and balances and financial performance. The NUTMON toolbox version 3.5 was considered the final NUTMON version (www.nutmon.org) and the revised tool was given a new name: Monitoring for Quality Improvement (MONQI; www.monqi.org).

MONQI is defined as a multi-scale and multi-disciplinary approach for monitoring management and performance of small-scale agricultural enterprises world-wide, with the aim of improving the quality of farm management, increasing crop production, improving product quality, improving livelihoods and protecting the environment. The rationale behind MONQI is that integrated monitoring of agricultural enterprises contributes to increased understanding of these enterprises and paves the way for improvements in social, economic, agricultural and environmental conditions. The toolbox consists of similar elements than the NUTMON toolbox (questionnaire, software and manuals) and the model approach is also similar, whereby each household/enterprise under study is disaggregated into units, activities and flows. The major difference with NUTMON is the wider range of issues that can be monitored:

- Activities such as fishing, hunting, gathering, processing and others, both agricultural and non-agricultural, in which the household (members) is (are) involved and that are not necessarily bound to on-farm land;
- Detailed information on sources and destinations of flows, allowing distinction of different markets;
- Household assets (house and other buildings, tools and means of transport, household and luxury goods) and sales, purchases, borrowing and lending, gifts;
- Loans (amount, source, purpose, repay period, amounts repaid per month) and savings;
- Services provided (off-farm labour, land rent received).

Users can add (an unlimited number of) questions to each of the distinguished units/activities in addition to the information gathered in MONQI by default. This additional information is stored in the database and exported with the other results. In addition software has been updated to further increase user-friendliness of the system. Analysis and reporting of the results can be done using regular data processing software or by user-defined farm reports using MONQI's reporting tool (WART).

The team aims at developing different profiles of MONQI for specific applications:

- MONQI-J: Joint Learning (Farmer Fields Schools, Integrated Nutrient Management)
- MONQI-E: Environment (nutrients, pesticides and non-timber forest products)
- MONQI-L: Livelihoods monitoring
- MONQI-C: Monitoring Agro-Food Chains for Certification

It is possible to incorporate aspects of the different profiles in a single monitoring approach.

Currently, the MONQI toolbox is being applied in the following project activities:

- KTDA/LIPTON, Sustainable Tea Project Kenya, where MONQI is used to monitor project impact, describe the importance of tea as component of the livelihoods and provide detailed farmer-specific reports as input for the learning process in Farmer Field Schools;
- Sustainable Use of Pesticides in Horticulture in Vietnam (SUPHORT), where MONQI is used to monitor actual pest management practices in water melon cultivation and to provide plot-specific information on pesticide use in comparison with pesticide use protocols;
- Provide Uprooted communities access to Livelihood and Health recovery (PULIH), where MONQI is used to monitor project impact and to provide detailed farm management reports for joint learning in focused group discussions;
- Development of Irrigated Agriculture in Lower Shabelle in Southern Somalia (DIALS), where MONQI is used to monitor project impact and to provide detailed farm management reports for joint learning in Farmer Field Schools;
- Rural Prosperity Initiative: Impact assessment on smallholders' income and livelihood on small-scale irrigation technology and value-chain development in Nepal, Cambodia, Ethiopia and Zambia (Bill Gates Foundation).

Major contributions of NUTMON/MONQI and future developments

One of the major innovations of NUTMON/MONQI is the structured and comprehensive conceptual framework to describe and quantitatively analyse farm management practices that has been applied to a wide variety of complex smallholder systems in Africa and Asia. It is this relatively simple and flexible framework that has attracted many researchers to take NUTMON as a starting point in analysing current farm management in general and nutrient management in particular. A thorough understanding of actual farm management practices is generally considered a prerequisite in any process of learning, change or innovation. The conceptual framework focuses on quantification of management and livelihood aspects, and thus complements the various qualitative and participative tools widely used to analyse and diagnose farming systems. Integration of biophysical, financial and livelihood aspects, as realised in the NUTMON approach, is essential for effective decision support at farm household scale.

NUTMON/MONQI provides a detailed description and analysis of farm management practices for scientists, service providers, as well as for farmers, both at individual and at group level. For scientists and NGO-staff, the results generated through NUTMON/MONQI provide detailed quantified information on individual farms and/or on groups of farms, that could be used for upscaling to higher scales such as farming systems, catchments, agro-ecological zones or administrative units provided the sample of farm households monitored is representative for (one or more of) these higher scales. However, up-scaling of some biophysical aspects such as erosion and leaching, from farm to higher scales needs specific approaches, if possible at all (Roy et al., 2003). Farm management data collected in a structured way may form important inputs for various simulation approaches, as well as for econometric studies, although this type of application of NUTMON data is relatively new. On the other hand, NUTMON/MONQI provides feedback information to individual farm households or groups of farmers on actual farm management practices and on specific biophysical, financial and livelihood performance indicators. Such information plays an essential role in the process of farmers' learning and eventually in farmers' empowerment. The quantitative information provided by NUTMON/MONQI complements farmers' observations, contributes to farmers' analyses and recording and supports the experiential learning process. The contribution to the learning aspects focuses on the changes in farm management practices realised over time, as well as on comparisons with other farm households in the neighbourhood or group. In comparison to many decision support systems, where results are products of often complicated simulations, NUMON/MONQI returns farmers' own data in an orderly way, with only limited additional calculations. Farmers' confidence in these results is relatively high and they are willing to use them in their learning and innovation processes. The generated farm management information also plays an important role in the learning process of extension staff and researchers with respect to the bio-physical, economic and social aspects of smallholder farming systems. Experience in the projects described in this thesis shows that the NUTMON tool stimulates linkages, interactions and cooperation between farm households and research staff in the process of innovation (Part 2, Chapter 6). It supports quantitative understanding of farm management practices by farm households, extension staff and researchers and facilitates communication about required processes and directions of change between farm households and researchers/extension staff .

This thesis has focused on the experiences with NUTMON focusing on nutrient management. As has been illustrated in the MONQI toolbox, other components in the dynamics of smallholder households, both agricultural and non-agricultural, can similarly be addressed. The current focus on linking smallholders to national and international markets increases their need to further optimise food production processes, through keeping records on their actual practices (use of pesticides), allowing traceability of products to farms, plots or animals and through assessing impacts on the environment, family livelihood, etc. The structured NUTMON/MONQI framework can be used to assist farmers in collecting the required information on management practices, both for their own learning as a basis for improving the production process and to generate the necessary information on the production process for consumers (certification).

A relatively new application focuses on quantitative impact assessment of projects or other interventions on smallholder farming systems. Appropriate indicators defined by the project or the implementing public or private organisation are calculated on the basis of information collected at smallholder farm households at two or more points in time. Examples are monitoring of the impact of project assistance on smallholder farming in Aceh (Indonesia) after the tsunami and impact assessment of a project in four countries in Asia and Africa on small-scale irrigation technology and market linkages in smallholder vegetable production systems. This application of NUTMON/MONQI as an impact assessment tool, following a baseline survey, needs further development, but seems promising.

Smallholder farmers play a key role in rural development in Africa and Asia. Many public and private actions are in progress in these continents and more are being planned to assist smallholders in optimising farm management (increase productivity and income), in sustainable use of natural resources (water, pest and soil fertility management), in improving market linkages, diversifying sources of income and reducing risks. The need for monitoring change and impacts, as well as for generating information to assist learning and innovation processes in smallholder enterprises may be expected, therefore, to increase in the future. Therefore further development of MONQI will be highly relevant to support rural development processes and should focus on the following aspects:

- Developing specific applications for assisting learning and innovation processes at farm household level, monitoring production processes in agro-food chains, environmental impact assessment and monitoring livelihood impacts;

- Continuous software development for effective data management and to improve user-friendliness;
- Simplify and improve analysis and reporting features.

Learning and innovation processes in smallholder agriculture in East Africa

Application and experiences in improving soil fertility management in East Africa

This shift towards participatory, discovery- and learning-based theories, as described in Part 1, has triggered development and implementation of various innovation, research and extension approaches:

- Farming Systems Research and Extension (FSR&E; Collinson, 2000)
- Rapid Rural Appraisal (RRA) and Participatory Rural Appraisal (PRA)
- Participatory Technology Development (PTD; Jiggins and De Zeeuw, 1992)
- Participatory Learning and Action Research (PLAR; Defoer and Budelman, 2000)
- Farmer Research Groups (FRG; Bruin and Meerman, 2001)
- Farmer Field Schools (FFS; Gallagher, 2003)

In the soil fertility management research and development activities in East Africa described in this thesis, all of the above-mentioned participatory learning-based approaches have been applied. However, the focus of attention shifted over time, in line with the developing insight in the international research community. Initially, the innovative aspects of NUTMON focused on studying actual farm management practices (farming systems context) as a basis for a better understanding of existing constraints, and identifying potentials for solutions (Part 3, Chapter 4). At that time, participation was limited to farmers supplying information. Limited attention was paid to providing feedback to farm households for learning or participatory action. This resulted in increased insights in smallholder farm management practices, but not in an actual process of change. The aspect of farm household participation gained momentum when the application of NUTMON was embedded in other diagnostic tools, such as PRA and participatory nutrient flow mapping, and linking this diagnostic phase to action research, at the time labelled Participatory Technology Development (Part 3, Chapters 5, 6 and 7). The NUTMON results were actively used in a process of participatory learning and understanding the impact of current farm management practices on soil fertility, and were a starting point for involving farm households in identifying and prioritising solutions. The farmers' active participation in diagnosis and experimenting was a major step in further developing their capacity to innovate and implement changes in their farming systems, and marked a radical change in the relation of farm households with researchers, extension agents and NGO-staff. Although most of the activities were implemented with groups of farmers, little attention was paid to the group organisational aspects. The focus was on individual learning and capacity building, which was conveniently implemented in groups of individuals. Only in the most recent projects, organisation of farmers was considered not only as a structured platform of learning and innovation, but also as a vehicle to address other aspects of farmers empowerment (Part 3, Chapter 8).

In the course of these developments, the importance and role of the NUTMON toolbox in the innovation process gradually decreased. With the increased focus on action research, more attention was given to tools and methodologies to develop the observation, experimentation, evaluation and reflection skills of farmers. On the one hand, this is a desirable development, since it forces scientists to involve farmers in all aspects of the research process, facilitates research priority setting to smallholder real problems and introduces the notion of accountability of research to the community to show results and bring about actual change in smallholder agriculture. On the other hand, there is a risk of underestimating the role of fundamental and empirical research in these new participative innovation systems. It is a rather romantic and unrealistic view that most of the innovations can be generated by farmers themselves. Smallholders also need to be inspired and triggered by innovations developed by (both, publicly- and privately-funded) research , which in turn can be inspired by the interaction with farmers to create innovations to solve problems smallholders are facing. The decision whether or not to adopt will always be with the client, in this case the smallholder farmer. New agricultural innovation systems should be characterised by methodological pluralism, making use of the relative strengths of the different approaches. In East Africa, examples of such pluralistic approaches are the African Highland Initiative and the reform of the National Agricultural Advisory Services in Uganda (NAADS; German and Stroud, 2007). Also the FFS approach described in this thesis is a successful example, integrating:

- Empirical research for problem identification, understanding and identifying opportunities with a crucial role for the NUTMON approach;
- Participatory action learning, to address problems through interactive cycles of diagnosing, actions, observations, reflections and re-planning, with action research superimposed to synthesize higher-level lessons (the FFS process);
- Empirical research to assess the impact of participatory processes through impact assessment (Part 3, Chapter 8).

However, the approach is not without pitfalls. Many examples in Eastern Uganda and Kenya have been observed where participatory learning processes tended to focus on the process, while achieving few innovative results and actual (technical) improvements in farm management practices or farm household livelihoods. Moreover, in on-farm experimentation, scientifically sound procedures should be used, in the participatory learning process, to ensure adequate innovative capacity building, as well as preventing misinforming smallholders.

Adequate evaluation of the various approaches in which NUTMON has been applied is not possible, as no systematic impact assessments were performed after the end of the projects. Only in the FFS approach (Part 3, Chapter 8) an impact assessment was conducted one year after the project ended. In the projects described, the innovation process focused on various soil nutrient adding technologies through combined application of mineral fertilizers and organic nutrient sources. The principles and effectiveness of these technologies were already known in the scientific community, but apparently had relatively little impact in smallholder agriculture. Fine-tuning the technologies and adapting them to local circumstances, as well re-directing the research agenda proved to be major contributions of the participatory experimenting and learning process. The impact assessment in the FFS project revealed relatively high adoption of technologies tested and discussed in the FFS, but moreover stressed the importance of increased knowledge and skills, the benefits of a strong organization and the importance of overall impact on livelihood (Part 3, Chapter 8).

Farmers Field Schools and innovation systems

The increased focus on farmer organisations proved a crucial step in the sustainability of innovation systems. Apart from the increased efficiency in dealing with groups rather than individual farm households, especially the role of the group process in learning, empowerment, access to information, inputs and markets, motivation and sustainability is essential. The sustainability of these farmer groups then becomes an important issue. Donor- or NGO-initiated groups focusing on a single issue tend to stand less chance to be sustained than groups already existing and addressing multiple-issues. The impact assessment of the FFS project showed that farmers' main motivation to maintain the group was the benefit of the joint commercial activities, with the research and learning activities as a secondary benefit. The increased access to markets as a result of acting as a group and the associated expected additional cash income was in this case the major driving force to continue participation in the FFS, including the joint research and learning activities. This leads to the conclusion that proper embedding of the participatory learning process in a broader agricultural food chain concept, especially including access to markets, will improve its performance, facilitate the motivation of farmers and increase the sustainability of the innovation system. Other experiences in Kenya support this conclusion. For instance, in a project in which smallholder farmers producing fruits and vegetables are linked to local exporters and traders for supermarkets and are eager to experiment and learn to cultivate 'new' crops (passion fruit, open-air 'summer' flowers, vanilla), change management practices to improve quality (tomatoes, cabbage), or comply with required phytosanitary standards (KHPD Newsletters). The same holds for a FFS project currently implemented with Lipton and the Kenyan Tea Development Authority, in which FFS of smallholder tea farmers are learning and testing sustainable tea practices (own observations). In both cases, learning and experimenting processes at smallholder enterprises are implemented enthusiastically, because results translate in a relatively short period of time into direct financial benefits due to the good market linkages. These experiences also call for increased flexibility in focus of FFS, dictated by the needs of the participants, rather than being determined by the objectives of a project, donor or public organisation.

The increased focus on participatory learning approaches implies a considerable change in the role of organisations and their staff involved in the agricultural innovation system (research institutions, extension staff, NGO's, private sector service providers). It requires a more dynamic, facilitating, flexible and client-oriented attitude, more direct interaction with farmers and spending more time in farmers' fields and moreover a willingness to share power over the research and activity agenda. At the same time, the FFS should maintain and further develop the disciplinary expertise required to address smallholder problems. Although the majority of the organisations in East Africa has adopted these participatory approaches and staff has been trained in the related tools and methodologies, the actual implementation of these changes in practice leaves much room for improvement. Very often, participatory tools are applied, after which the routine researcher-managed on-farm research procedures are continued or NGO's continue to push their ideologically-based messages. Pilot projects often manage to realise the required change in attitude, but a large-scale shift of power and accountability towards the smallholders clients remains yet to take place, despite the participatory rhetoric in the research and development community (Pijnenburg, 2004; Chambers, 1995). Government policy can facilitate this process, as is shown in the implemented policy reforms in Uganda, focusing on decentralisation of the research and extension system. But also a more general focus on building participatory approaches attitudes in curricula in primary and secondary education and agricultural colleges and universities is necessary.

The FFS is currently one of the most comprehensive and widely adopted approaches for research and participatory learning (Braun et al., 2006). Initially started with a technical focus on IPM it has currently widened its scope to a variety of (rural) development processes (Fig. 1).

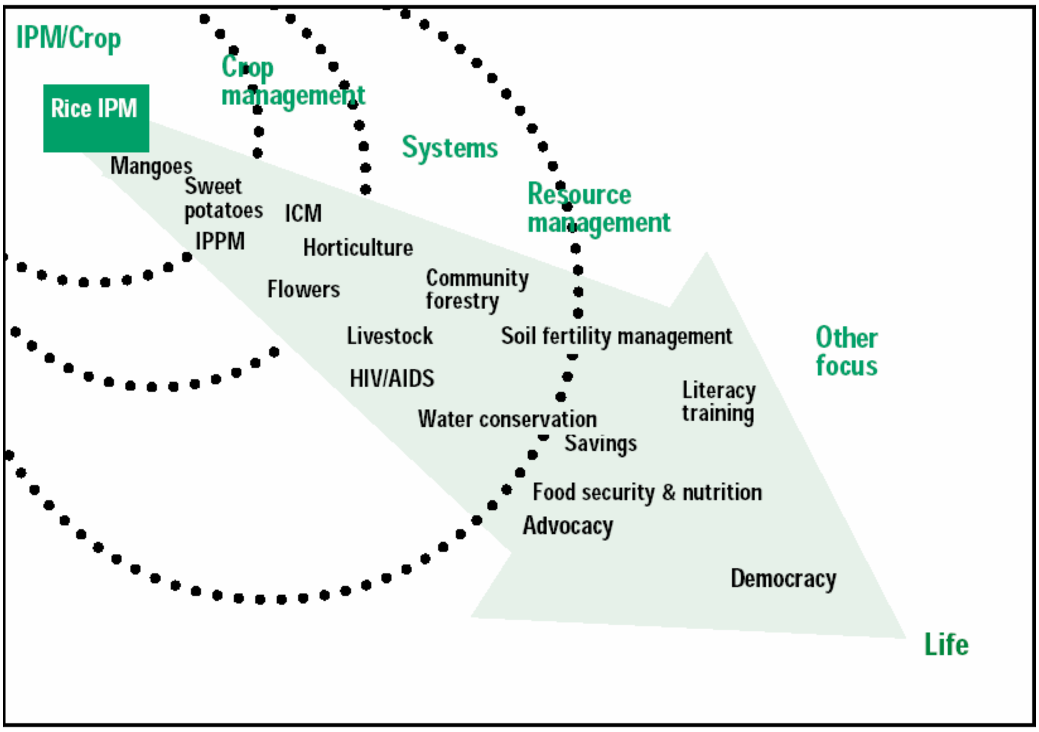


Fig. 1 Widening focus of FFS applications from single constraint to social-cultural dimensions of community life (CIP-UPWARD, 2003)

The FFS encompasses most of the earlier developed and applied participatory approaches, and many elements such as RRA, PTD and FRG are applied in FFS. Despite the ongoing debate on its effectiveness and sustainability, the FFS approach is widely considered to be a highly valuable contribution to the development of effective and client-oriented innovation systems in agricultural and rural development in East Africa (Part 3, Chapter 8). The experiences in nutrient management have shown its effectiveness, witnessed by increased technical knowledge of the participants, resulting in actual and measurable changes in fertility management practices, but also by the potential in being a stepping stone to improved and sustainable farmer organisations, farmer empowerment and market linkages.

Given the experiences in the project described in this thesis, FFS should not be considered as a new approach to agricultural extension, which despite all rhetoric, is still largely focused on ‘technology transfer’, a view shared by other FFS experts (Gallagher et al., 2006). The main potential of FFS lies in the combined role of contributing to farmer organisation, farmer empowerment and facilitating active farmers’ participation in agricultural innovation systems. Recent criticisms state that FFS are donor-driven, financially unsustainable and difficult to up-scale (Davies, 2006). However, when FFS develop into a bottom-up, farmer-led movement these issues can easily be addressed. Experiences in the project described in this thesis and elsewhere in East Africa show that self-financed FFS are viable through the integration of joint commercial cash generating activities by the FFS or through loans rather than grants (Braun et al., 2006; Okoth et al., 2002). In conclusion: FFS is in potential an appropriate approach, enabling farmers to play an active role in agricultural innovation systems.

Some weak points, however, need to be addressed in order to develop FFS in a widely acceptable method for discovery-based interactive learning processes. These points are: existing variations in relevant capacities of facilitators, the relatively limited participation of the most vulnerable groups in society (Gallagher et al., 2006) and the rigid formalised structures of FFS (Isubikalu, 2007). To realise a drastic change in the agricultural innovation systems in general and for up-scaling FFS in particular, initially an adequate number of facilitators needs to be available that are capable of integrating local knowledge and external science-based knowledge with client-service orientation, and are able to handle participatory group processes. In most research and extension organisations in East Africa, the relevant capability is still scarce. Within NGO's, in general relatively more qualified and experienced facilitators are available. Support, training and networking programmes, as initiated in East Africa and elsewhere (www.farmerfieldschool.info) are therefore urgently needed. FFS have been found to work best in the context of a demand-driven extension policy process and in a policy environment that encourages organisational growth and favourable market conditions for smallholders. Own observations also show that FFS work best in high potential agro-ecological zones and in sectors with good linkages to markets, such as horticulture and tea. Farm households with limited resources or poor market connections and in areas with marginal conditions for agriculture are less likely to participate in and profit from FFS processes. For the most vulnerable groups it may therefore be necessary to facilitate the establishment of FFS specifically focused on their needs, with more initial support from public institutions. The formalised rigid structures characterizing the majority of FFS in East Africa facilitate up-scaling and guide inexperienced facilitators through the various participatory and client-oriented process. However, to actually turn FFS into an open and dynamic instrument in a well-functioning innovation system, it needs to reduce its dependence on dogmatic internal organisations, rules, methods and procedures. In this thesis, an example is presented of modified methods and procedures to accommodate the specific needs in soil fertility management research and address the objectives of the partners in the process. This will require creative (re-)thinking by organisations and institutions currently involved in promoting and supporting FFS.

Towards effective innovation systems in smallholder agriculture

The current innovation systems, composed of relatively compartmentalised groups of actors (farmers, formal research institutes, applied research and extension, service providers, NGO's) cannot cope with the diverse and rapidly changing ecological and economic environment in rural Africa. New institutional arrangements are required to effectively link the relevant actors to ensure effective innovation processes and market-oriented developments in smallholder agriculture.

Effective creation and application of knowledge occurs in configurations, in which various stakeholders, including knowledge organisations, have different roles, depending on their comparative advantages. As has been demonstrated in this thesis, smallholder farmers, as major stakeholders, need to play an active role to ensure that such an innovation system effectively addresses the challenges of smallholder agriculture. Three configurations are distinguished that combined, in an iterative process of exchange of information and products, constitute the innovation system: consultative platforms, implementation coalitions and science networks (Fig. 2).

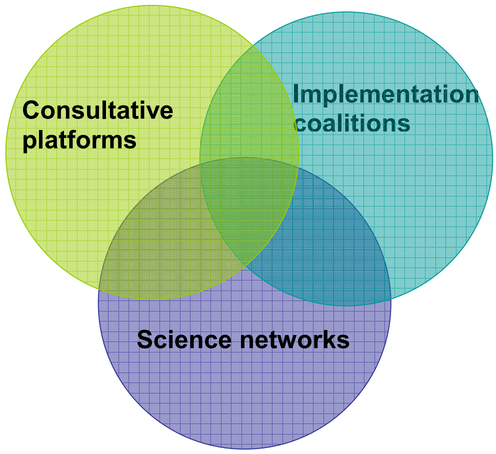


Fig. 2 Three configurations and their interactions in an innovation system (DLO, 2005)

Key to the well-functioning of the innovation system is the existence of effective mechanisms that arrange the flow of knowledge, information and products between the different configurations. The participation of knowledge organisations in consultative platforms and implementation coalitions engages knowledge organisations in learning alliances with stakeholders in processes of innovation and research and will guide the research agenda in the science networks. Transforming the innovation systems in learning alliances with stakeholder should lead to increased effectiveness of the activities, demand-driven research and appropriate products.

Consultative platforms can be multi-stakeholder platforms, including public-private and government-civil society linkages. Their main functions are to jointly identify and prioritise knowledge gaps, evaluate technological innovations through modelling and scenario studies and/or monitoring and testing in an experimental setting and design new institutional structures to realise technical change. In implementation coalitions the main focus is on optimizing innovation processes, i.e. putting options in context, and learning from experiments. Science networks, of an open and exploratory nature, are effective in their functions of empirically investigating and developing baskets of options. Scientists collaborate to increase insights in functioning of the smallholder agricultural systems, to develop technologies and methods, and to broaden their horizon in developing options.

Farmers Fields Schools are an effective, relatively well-established, and in some countries institutionalised, form of an implementation coalition. The agricultural science networks are relatively well-established in East Africa and are gradually becoming involved in implementation coalitions such as FFS and increasing the influence of stakeholders on the research agenda. Institutionalised consultative platforms are yet the major bottleneck. Often, only ad-hoc and temporary multi-stakeholder platforms are established around projects and programmes. Always, there is a need for continuous prioritisation, monitoring and evaluation of the performance of the innovation system by stakeholders.

The experiences described in this thesis and elsewhere indicate that such new coalitions work best in circumstances where smallholders are well integrated in, or can easily be linked to local, regional and/or international markets. The financial incentives for technology development, value addition within the chain and strengthening of bargaining power in established groups are driving forces for smallholders, service providers and private sector parties to invest time and resources in such new innovation systems. In more marginal areas with a higher degree of subsistence-oriented agriculture, initiation of such a process may be more difficult, but not less relevant. It will be more difficult, since technical margins for improvement are small and financial incentives often limited or uncertain, while the interest of the private sector to participate in this process is limited. But given this more difficult situation, especially in these areas the need exists for a client-oriented, region-specific approach to innovation. The project in the semi-arid areas in Kenya (Part 3, Chapter 7) showed that most of the soil fertility improvement technologies proposed and developed by the science network were financially unattractive and risky when implemented in smallholder farming systems. Interventions in the facilitating environment, improvements in supporting institutions and support in development of non-farm activities appeared much more appropriate. A well-functioning consultative platform should have been able to identify the specific needs for the smallholders in these semi-arid areas much more effectively. In marginal areas, therefore, a more pro-active involvement of public organisations is needed to initiate the development of such coalitions.

Most of the FFS and their facilitators focus on agro-technical issues, while it is argued that the benefits of FFS may be equally important in other aspects such as establishing farmer organisations, increasing farmer empowerment and linking to inputs and outputs markets. It is especially the latter aspect that is the basis for the continuing interest of smallholders to participate in FFS. Hence, in a revised innovation system, a more balanced attention is needed to the diverse potential functions and roles of a FFS to realise up-scaling of the approach. Although most of the existing FFS manuals for facilitators still focus on technical issues, examples of applications in other relevant livelihood aspects such as market linkages, health and environmental issues are encouraging.

Do well-integrated innovation systems at national level exist already? In Kenya a start has been made with the establishment of consultative platforms, implementation coalitions, science networks and their integration at national level, through the Agricultural Technology and Information Response Initiative (ATARI), initiated by the Kenya Agricultural Research Institute (KARI), and the mainstreaming of the FFS approach. At sector level, a permanent public-private horticultural task force is operational, identifying constraints and required actions and performing project and donor coordination (permanent consultative platform). Smallholder producers, jointly with private sector (exporters) and/or public institutions/NGO's, initiate activities on production and post-harvest technology development, establish and improve linkages to markets, learn about new issues, such as food safety standards and EurepGAP certification and experiment with sorting and grading (implementation coalition). The link to the research network exists, but is still relatively weak.

Towards sustainable rural livelihood strategies in East Africa

Do the developed approaches and the experiences gained in using them in nutrient management research and development contribute to improved and sustainable rural livelihoods in East Africa? To address this question, the sustainable livelihood framework developed by DFID is used, whereby a livelihood comprises the capabilities, assets (including both, material and social resources) and activities required for a means of living (Fig. 3). A livelihood is sustainable when it can cope with and recover from stresses and shocks and maintains or enhances its capabilities and assets both now and in the future, while not undermining the natural resource base (Carney, 1998).

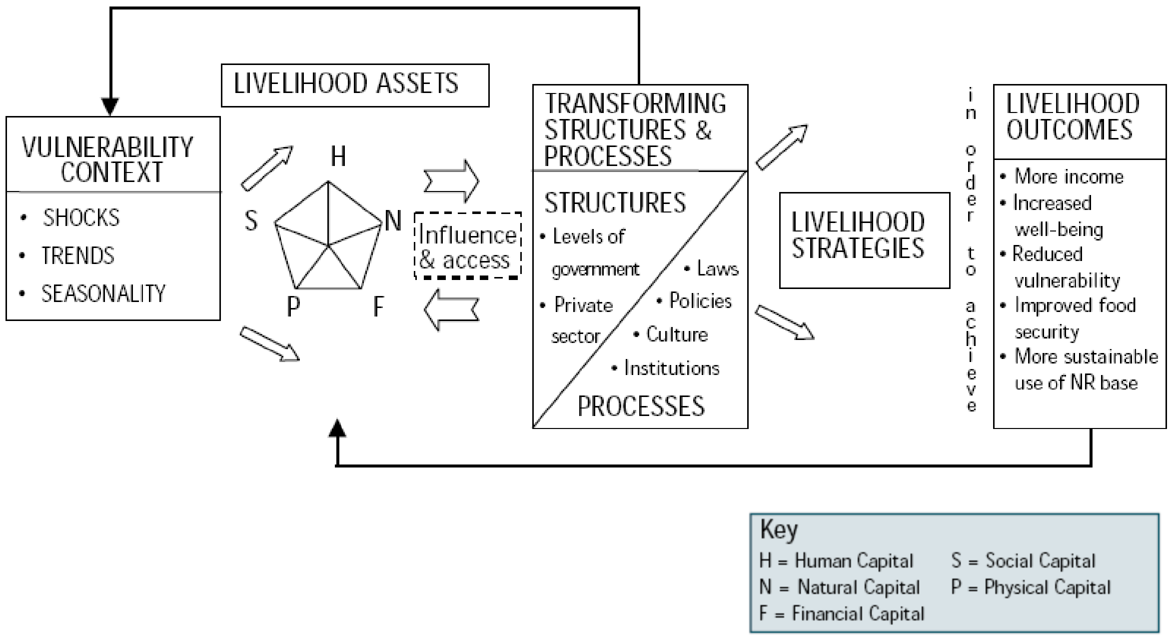


Fig. 3 Sustainable livelihood framework

Important elements are the dynamic (vulnerability) context in which farm households operate, the assets of the farm households to deal with the context and structures and processes that may support or hamper them in these endeavours. The dynamic context consists of trends and changes in economic conditions, resource use, technologies and population, while also sudden changes or shocks (illness, drought, conflict) and seasonality of prices, production or employment opportunities play a crucial role. Apart from the obvious natural, physical and financial assets, an important role is assigned to human assets such as health, formal and informal education, knowledge, as well as social assets such as interactions, relationships and networks. Many existing public and private structures and institutions and the way they operate (processes) have a major influence on the options for smallholders to improve their livelihoods. Also having access to these institutions (extension, inputs, credit) or the ability to influence them are crucial in this process.

When addressing rural livelihoods in East Africa, it is important to consider the existing variations in physical context (soil, climate) and in infrastructure (markets). Although realising the heterogeneous micro-environment in East African agriculture, a global classification is useful to enable an assessment of development options. Recently, two such global classifications were made by IFPRI and ASARECA (Omamo et al., 2006; Pender et al., 2006). One study classified the East African region (Sudan, Ethiopia, Kenya, Uganda, DRC, Rwanda, Burundi, Tanzania and Madagascar) according to population density, agricultural potential and market access and arrived at four major development domains (Table 1).

Table 1 Distribution of development domains in East Africa

Domain			Rural Population (%)	Cropped Area (%)
Population density	*Agricultural Potential*	*Market access*		
H*	H	H	14	7
H	L	H	15	9
H	L	L	28	39
L	L	L	15	16
Rest			28	29

Source: adapted from Omamo et al., 2006
*H = high; L = low

It is obvious that the largest share of the rural population in East Africa lives in areas with relatively low agricultural potential and low access to markets, while only a minority enjoys a high agricultural potential combined with high market access. In Kenya, however, where the majority of the studies in this thesis were implemented, a much higher number of people and a higher share of the cropped land is situated in the more favourable areas (HHH).

Smallholder agriculture in East Africa in general has been confronted with the following trends:

- Declining labour productivity in agriculture;
- In general, consumption exceeds production for most agricultural products (except for coffee, tea, fruits and vegetables);
- The share of East Africa in global agricultural exports is declining steadily (mainly due to the declining share of coffee exports);
- Poverty rates are increasing and hunger and malnutrition aggravating due to population growth;
- Declining size of land holdings;
- Slow growth of non-agricultural employment;
- Increasing variability in climate, with less predictable start and ending of rainy seasons;
- Mixed developments concerning access to input and output markets (Omamo et al., 2006).

In the last decade, on the other hand, conflicts have subsided, and the political environment has stabilized, with encouraging signs of economic integration between a few economies (Kenya, Uganda, Tanzania, Rwanda and Burundi). Overall, the conclusion emerges that gradually the context for smallholders in East Africa has become less conducive.

The project activities described in the thesis zoomed in on the following aspects of the sustainable livelihood framework:

- Human assets, by developing experiential learning capacity and knowledge on nutrient management;
- Social capital, through the formation of FFS, providing smallholders with improved relations and networks and better access to information and markets;
- Natural assets, through actual improvements in soil nutrient balances and soil fertility;
- Improvement of influence on and access to research information and the private sector through FFS activities;
- Influencing policies and policy makers to improve the enabling environment of smallholders.

These activities were implemented in pilot projects, in regions representative for the major development domains in East Africa:

- HHH: pilots in Embu (Part 2, Chapters 2 and 3) and Kiambu (Part 3, Chapter 8) Districts in Kenya;
- HHL: pilots in Western Kenya (Part 2, Chapters 2 and 3) and Western Uganda (Part 3, Chapter 6);
- HLH: pilots in Machakos District, Kenya (Part 3, Chapters 5 and 6);
- HLL and LLL: pilots in semi-arid areas in Kenya (Part 3, Chapters 7 and 8) and Eastern Uganda (Part 3, Chapter 6).

In the densely populated areas with high agricultural potential and easy access to large urban markets, the impacts on livelihood have been most positive. An upward spiral can be realised, where increased production of high-value agricultural commodities, complemented by increased non-farm activities, contributes to increased family incomes and increased ability and willingness to invest in land-improving and productivity-increasing technologies. In Central Kenya, this process is stimulated by a large and growing market in Nairobi, a relatively good infrastructure and proximity of processing facilities, cooperatives providing credit and the presence of local merchants with (international) trading experience and relationships with exporters. Although no specific research was done on this aspect, the business-like attitude and characteristics of the population in the Kenyan Central Highlands also appear to contribute to the success. In these conducive circumstances, the activities initiated in nutrient management and Farmers Field Schools, have made a considerable contribution to further improvements in the livelihood of smallholders and to a more sustainable resource base, through effectively addressing declining soil fertility. Although being the Province with the lowest poverty rate in Kenya, still an average of 30% of the population lives below the poverty line (CBS, 2003). More specific attention therefore needs to be paid to identification of the specific needs and possible points of intervention to further improve the livelihood of the poorest in these relatively favourable areas.

In all other identified areas, the environment for smallholders is less conducive. The high potential areas with relatively difficult market access and weak networks obviously require development of market infrastructure and institutions, such as roads, transportation, market information systems, etc. However, it will be difficult to engage in high-value perishable agricultural products and therefore innovation systems should focus on less perishable commodities, value-adding through processing and livestock, while continuing attempts to improve productivity of existing agricultural commodities in the area. For the areas with lower agriculture potential and limited market access, the options to adding value and accessing new markets are severely limited. Investing in inputs and technologies is often financially unattractive. Innovation systems should focus on livestock improvement, small-scale irrigation, water harvesting, improved management of communal lands and promotion and development of drought-resistant crop varieties. However, the agricultural sector in these areas has limited potential and an integrated focus on attracting investments and developments in the non-farm sector should receive high priority in order to sustain livelihood in these areas. Otherwise, migration to urban and high agricultural potential areas will continue.

To improve livelihoods of the rural population in East Africa, priority should be given to the development of a broad range of livelihood assets. This will enable smallholders to initiate activities themselves, and not continue to be dependent on outside interventions. It has been demonstrated that this goes beyond the physical and natural capital, traditionally the focus of most of the technical assistance and interventions. The development of participatory experiential learning approaches and farmer organisations, resulting in new arrangements in innovations systems, needs mainstreaming. Emphasis should be given to up-scaling the various experiences in pilot activities and integrate these in national agricultural development policies, research organisations and rural institutional development.

Our research has shown that, once smallholders are equipped with knowledge and the capacity to learn, are empowered in organizations and connected to markets and the private sector, they can substantially improve their rural livelihoods. A conducive environment, however, is necessary to fully exploit this potential of the smallholder agricultural sector, as has been stated over and over in policy documents and research reports. Experiences described in this thesis and from other projects in the same region, show that many components of the rural economy need to function well in order to realise such a conducive environment (Place et al., 2005). Confronted with variable and low prices for agricultural products, droughts, labour shortages through the HIV/AIDS pandemic, small land sizes, limited access to markets and information, even well-empowered and knowledgeable farm households find it difficult to sustain a livelihood or stay out of poverty.

Actual efforts and results from research and development organisations to improve the enabling environment have so far been very limited and are often referred to by researchers and NGO's as exogenous factors or left to the initiative of policy makers. To actually make a contribution to improved rural livelihood in Africa, research and development organisations can and should contribute to improve the conducive environment, through actions such as:

- Explore and support development of effective forms of producers' organisations and linkages to private sector organisations;
- Identification of options to reduce transaction costs in agro-food chains;
- Identification of effective price polices in input and output markets;
- Identification of options to reduce price and climate risks for smallholders;
- Identification of rules, regulations, red-tape and administrative measures that constrain smallholders in doing business;
- Identification of entry points for crucial private investments;
- Explore new agro-food chain configurations that will allow smallholder participation in national, regional and international markets;
- Identify options for public-private partnerships;
- Explore technical options for product and market differentiation.

The need for research in technical issues (agronomy, biotechnology, soils, IPM, etc) remains strong in order to increase the productivity and sustainability of the smallholder farming systems. But the technical research agenda needs to be imbedded in new innovation systems to become more demand-oriented and linked to activities focusing on creating and improving a conducive environment.

Although non-farm income is becoming increasingly important all throughout rural East Africa, especially in the areas with low agricultural potential, development of viable non-farm activities should receive priority. Specific focused public policies and measures need to be developed to stimulate private investments in areas such as small scale manufacturing, processing, and tourism.

Concluding remarks

The experiences documented in this thesis have shown that the structured conceptual framework and the related NUTMON toolbox facilitate a comprehensive description and analysis of management practices in general and nutrient management aspects in particular, in complex smallholder farming systems. The quantitative estimation of comprehensive nutrient balances and the inclusion of financial aspects, based on farmers' own data and observations, complements other existing participative tools and contributes to learning and innovation processes at farm household level.

Our research has shown that, once smallholders are equipped with knowledge and the capacity to learn, are empowered in organizations and connected to markets and the private sector, they can substantially improve their rural livelihoods. Therefore a focus on participatory experiential learning approaches and farmer organizations that result in new arrangements in innovation systems needs to be mainstreamed in rural development projects.

Literature

Abegaz. A., 2005. Farm management in mixed crop-livestock systems in the Northern Highlands of Ethiopia. Ph.D. Thesis, Wageningen University, Wageningen.

Bekunda, M. and Manzi, G., 2003. Use of partial nutrient budget as an indicator of nutrient depletion in the highlands of southwestern Uganda. Nutrient Cycling in Agroecosystems 67: 187-195.

Braun, A., Jiggins, J, Röling, N., Van den Berg, H. and Snijders, P., 2006. A global survey and review of Farmer Field School experiences. Endelea, Wageningen, The Netherlands.

Bruin, G.C.A. and Meerman, F., 2001. New ways of developing agricultural technologies: the Zanzibar experience with participatory Integrated Pest Management. WUR/CTA, Wageningen, the Netherlands, 167 pp.

Cabral, L., Farrington, J. and Ludi, E., 2006. The Millennium Villages Project – a new approach to ending rural poverty in Africa?. Natural Resources Perspectives 101, ODI, London, UK.

Carberry, P.S., Adiku, S.G.K., McCown, R.L. and Keating, B.A., 1996. Application of the APSIM cropping systems model to intercropping systems. In: Ito, C., Johansen, C., Adu-Gyamfi, K., Katayama, K., Kumar-Rao, J.V.D.K. and Rego, T.J. (Eds.), Dynamics of Roots and Nitrogen in Cropping Systems of the Semi-arid Tropics, Japan International Research Centre for Agricultural Science, ICRISAT, Hyderabad, pp. 637–648

Carney, D. (Ed.), 1998. Sustainable Livelihoods: What contribution can we make? Department for International Development (DFID), London, UK.

CBS (Central Bureau of Statistics Kenya), 2003. Geographic dimensions of well-being in Kenya; Where are the poor? From districts to locations, Volume 1. Nairobi, Kenya

Chambers, R., 1995. Paradigm shifts and the practice of participatory research and development. In: Nelson, N. and Wright, S., Power and Participatory Development, Intermediate Technology Publications, London.

CIP-UPWARD, 2003. Farmer Field Schools: From IPM to Platforms for Learning and Empowerment. Users' Perspectives With Agricultural Research and Development. International Potato Center, Los Baños, Laguna, Philippines, 87 pp.

Coleman, K. and Jenkinson, D.S., 1995. RothC-26 3. A Model for the Turnover of Carbon in Soil: Model Description and Users Guide. IACR, Rothamsted, Herts, UK, 30 pp.

Collinson, M. (Ed.), 2000. A History of Farming Systems Research. FAO, Rome, Italy and CABI Publishing, Wallingford, UK, 432 pp.

Davies, K., 2006. Farmer Field Schools: a boon or bust for extension in Africa? Journal of International Agricultural and Extension Education 13(1): 91-97.

Defoer, T. and Budelman, A., 2000. In: Defoer, T. and Budelman, A. (Eds.), Managing Soil Fertility in the Tropics. A Resource Guide for Participatory Learning and Action Research, Royal Tropical Institute, Amsterdam, The Netherlands/International Institute for Environment and Development, London, UK.

De Ridder, N., 1997. Hierarchical levels in agro-ecosystems: selective case studies on water and nitrogen. Ph.D. thesis, Wageningen Agricultural University, Wageningen, The Netherlands.

De Ridder, N., Breman, H., Van Keulen, H. and Stomph, T.J., 2004. Revisiting a 'cure against land hunger': soil fertility management and farming systems dynamics in the West African Sahel. Agricultural Systems 80: 109-131.

DLO-Foundation, 2005. Position Paper for LNV Policy Support Research Cluster Development Cooperation and International Agreements. DLO/Wageningen UR, Wageningen, The Netherlands

Esilaba, A.O., Nyende, P., Nalukenge, G., Byalebeka, J.B., Delve, R.J. and Ssali, H., 2005. Resource flows and nutrient balances for crop and animal production in smallholder farming systems in eastern Uganda. Agriculture, Ecosystems and Environment 109: 192-201.

Faerge, J. and Magid, J., 2004. Evaluating NUTMON nutrient balancing in Sub-Saharan Africa. Nutrient Cycling in Agroecosystems 69: 101–110.

FAO, 2003. Scaling soil nutrient balances; enabling mesolevel applications for African realities. FAO Fertilizer and Plant Nutrition Bulletin No.15, FAO, Rome, Italy.

Gallagher, K.D., 2003. Fundamental Elements of a Farmers Field School. LEISA Magazine Vol.19 (1): 5-6.

Gallagher, K., Braun, A.R. and Duveskog, D., 2006. Demystifying Farmer Field School Concepts. ECAPAPA Newsletter 9(6).

German, L. and Stroud, A., 2007. A framework for the integration of diverse learning approaches: operationalizing agricultural research and development linkages in East Africa. World Development 35: 792-814.

Giller, K.E., Rowe, E.C., De Ridder, N. and Van Keulen, H., 2006. Resource use dynamics and interactions in the tropics: Scaling up in space and time. Agricultural Systems 88: 8–27.

Haileslassie, A., Priess, J.A., Veldkamp, E. and Lesschen, J.P., 2006. Smallholders' soil fertility management in the Central Highlands of Ethiopia: implications for nutrient stocks, balances and sustainability of agroecosystems. Nutrient Cycling in Agroecosystems 75: 135–146.

Hengsdijk, H. and Kruseman, G., 1992. Operationalizing the DLV program: an integrated agro-economic and agro-ecological approach to a methodology for analysis of sustainable land use and regional agricultural policy. Report 1, DLV-DLO, Wageningen, The Netherlands.

Howard, J., Crawford, E., Kelly, V., Demeke, M. and Jeje, J., 2003. Promoting high-input maize technologies in Africa: the Sasakawa-Global 2000 experience in Ethiopia and Mozambique. Food Policy 28: 335-348.

Isabirye, M., Ruysschaert, G., Van Linden, L., Poesen, J., Magunda, M.K. and Deckers, J., 2007. Soil losses due to cassava and sweet potato harvesting: A case study from low input traditional agriculture. Soil & Tillage Research 92: 96–103.

Isubikalu, P., 2007. Stepping-stones to improve upon functioning of participatory agricultural extension programmes. PhD Thesis, Wageningen Academic Publishers, Wageningen, The Netherlands.

Jagtap, S.S., Abamu, F.J. and Kling, J.G., 1999. Long-term assessment of nitrogen and variety technologies on attainable maize yields in Nigeria using CERES-maize. Agricultural Systems 60: 77–86.

Janssen, B.H., Guiking, F.C.T., Van der Eijk, D., Smaling, E.M.A., Wolf, J. and Van Reuler, H., 1990. A system for Quantitative Evaluation of the Fertility of Tropical Soils (QUEFTS). Geoderma 46: 299-318.

Jiggins, J. and De Zeeuw, H., 1992. Participatory Technology Development in Practice: process and methods. In: Reijntjes, C., B. Haverkort and A. Waters-Bayer (Eds.). Farming for the Future: an introduction to LEISA. Macmillan, London, UK, pp. 135-161.

Kanté, S., 2001. Gestion de la fertilité des sols par classe d'exploitation au Mali Sud. Ph.D. Thesis, Wageningen University, Wageningen.

Keating, B.A., Carberry, P.S., Hammer, G.L., Probert, M.E., Robertson, M.J., Holzworth, D., Huth, N.I., Hargreaves, J.N.G., Meinke, H., Hochman, Z., McLean, G., Verburg, K., Snow, V., Dimes, J.P., Silburn, M., Wang, E., Brown, S., Bristow, K.L., Asseng, S., Chapman, S., McCown, R.L., Freebairn, D.M. and Smith, C.J., 2003. An overview of APSIM, a model designed for farming systems simulation. European Journal of Agronomy 18: 267–288.

Kuiper, M., Meijerink, G. and Eaton, D., (in press). Rural Livelihoods: Interplay between Farm Activities, Non-Farm Activities and the Resource Base. In: Kuiper, M., Van Keulen, H., Roetter, R.P. and Verhagen, J. (Eds.), Science for Agriculture and Rural Development in the South. Springer-Verlag, Dordrecht, The Netherlands.

Okoth, J.R., Khisa, G.S. and Julianus, T., 2002. The journey towards self-financed Farmer Field Schools in East Africa. Paper presenter at International Learning workshop on Farmer Field Schools: emerging issues and challenges, Yogyakarta, Indonesia.

Omamo, S.W., Diao, X., Wood, S., Chamberlin, J., You, L., Benin, S., Wood-Sichra, U. and Tatwangire, A., 2006. Strategic Priorities for Agricultural Development in Eastern and Central Africa. Research Report 150, IFPRI, Washington D.C., USA.

Onwonga, R. and Freyer, B., 2006. Impact of Traditional Farming Practices on Nutrient Balances in Smallholder Farming Systems of Nakuru District, Kenya. Presentation at conference on prosperity and poverty in a globalised world - challenges for agricultural research, Tropentag, October 11-13, 2006, Bonn, Germany.

Pender, J., Place, F. and Ehui, S. (Eds.), 2006. Strategies for sustainable land management in the East African Highlands. IFPRI, Washington D.C., USA.

Pijnenburg, B.F.M., 2004. Keeping it vague, Discourses and practices of participation in rural Mozambique. PhD Thesis, Wageningen University, Wageningen, The Netherlands.

Place, F., Adato, M., Hebinck, P. and Omosa, M., 2005. The impact of Agroforestry-based soil fertility replenishment practices on the poor in Western Kenya. Research Report 142, IFPRI, Washington D.C., USA.

Ramisch, J., 1999. In the balance? Evaluating soil nutrient budgets for an agro-pastoral village of Southern Mali. Managing Africa's Soils No. 9, International Institute for Environment and Development, London, UK.

Roy, R.N., Misra, R.V., Lesschen, J.P. and Smaling, E.M.A., 2003. Assessment of soil nutrient balance. Approaches and methodologies. FAO Fertilizer and Plant Nutrition Bulletin 14, FAO, Rome, Italy.

Saidou, A., Janssen, B.H. and Temminghoff, E.J.M., 2003. Effects of soil properties, mulch and NPK fertilizer on maize yields and nutrient budgets on ferralitic soils in southern Benin. Agriculture, Ecosystems and Environment 100: 265–273.

Schlecht, E. and Hiernaux, P., 2004. Beyond adding up inputs and outputs: process assessment and upscaling in modeling nutrient flows. Nutrient Cycling in Agroecosystems 70: 303-319

Scoones, I. and Toulmin, C., 1998. Soil nutrient balances: what use for policy? Agriculture, Ecosystems and Environment 71: 255-267

Sheldrick, W.F., Syers, J.K. and Lingard, J., 2002. A conceptual model for conducting nutrient audits at national, regional, and global scales. Nutrient Cycling in Agroecosystems 62: 61–72.

Smaling, E.M.A. and Dixon, J., 2006. Adding a soil fertility dimension to the global farming systems approach, with cases from Africa. Agriculture, Ecosystems and Environment 166: 15-25.

Stoorvogel, J.J., 2007. From nutrient balances to soil organic matter dynamics. In: Van der Zijpp, A.J., J.A.J. Verreth, Le Quang Tri, M.E.F. van Mensvoort, R.H. Bosma and M.C.M. Beveridge (Eds.), Fishponds in farming systems. Wageningen Academic Publishers, Wageningen, The Netherlands.

Stoorvogel, J.J., Antle, J.M., Crissman, C. C. and Bowen, W., 2004. The Tradeoff Analysis Model: Integrated Bio-Physical and Economic Modeling of Agricultural Production Systems. Agricultural Systems 80: 43-66.

Stoorvogel, J.J., Antle, J.M., De Jager, A. and Crissman, C.C., 2005. Tradeoff Analysis as an operational and accepted tool for policy analysis. Final Report Ecoregional Fund, Wageningen, The Netherlands.

Struif Bontkes, T., 1999. Modelling dynamics of agricultural development: a process approach – the case of Koutiala (Mali). PhD thesis, Wageningen University, Wageningen, The Netherlands.

Surendran, U., Murugappan, V., Bhaskaran, A. and Jagadeeswaran, R., 2005. Nutrient Budgeting Using NUTMON - Toolbox in an Irrigated Farm of Semi Arid Tropical Region in India - A Micro and Meso Level Modeling Study. World Journal of Agricultural Sciences 1: 89-97.

Tittonell, P., Vanlauwe, B., Leffelaar, P.A., Rowe, E.C. and Giller, K.E., 2005. Exploring diversity in soil fertility management of smallholder farms in western Kenya; I. Heterogeneity at region and farm scale. Agriculture, Ecosystems and Environment 110: 149-165.

Tittonell, P., Leffelaar, P.A., Vanlauwe, B., Van Wijk, M.T. and Giller, K.E., 2006. Exploring diversity of crop and soil management within smallholder African farms: A dynamic model for simulation of N balances and use efficiencies at field scale. Agricultural Systems 91: 71-101.

Tittonell, P., Zingore, S., Van Wijk, M.T., Corbeels, M. and Giller, K.E., 2007. Nutrient use efficiencies and crop responses to N, P and manure applications in Zimbabwean soils: Exploring management strategies across soil fertility gradients. Field Crops Research 100: 348–368.

VARINUTS, 2000. Spatial and temporal variation of soil nutrient stocks and management in sub-Saharan African farming systems. Consolidated Scientific Report to EU DG12, SC-DLO, Wageningen, The Netherlands.

Wijnhoud, J.D., 2007. Nutrient budgets, soil fertility management and livelihood analysis in Northeast Thailand: a basis for integrated rural development strategies in developing countries. PhD thesis, Wageningen University, Wageningen, The Netherlands, 197 pp.

Summary

Maintaining and improving soil fertility is crucial for Africa to attain the Millennium Development Goals. Fertile soil and balanced soil nutrient management are major foundations for sustainable food production, contribute to a sound management of natural resources and assist in controlling environmental degradation such as erosion, loss of biodiversity, pollution of water sources and acidification. It has been recognized that activities on soil fertility management need to be implemented within an overall strategy to overcome poverty that includes restoring budgetary priority to agriculture as an engine of economic growth, empowering women, and promoting community-based hunger-reduction actions, improve nutrition, develop rural markets and infrastructure, and promote environmental sustainability. While formal agricultural research has generated a vast amount of knowledge and fundamental insights in soil fertility and ways to enhance it, application of these results by smallholder farmers remained below expectations. New approaches are needed that actively include smallholders in the process, focus technology development and innovations to the specific physical, climatic, economic and social circumstances of smallholders and integrate technology development in a process of improving the conducive environment for smallholders in doing business.

Soil nutrient depletion as a serious threat to the sustainability of the productivity of African farming systems was put on the agenda of policy makers and the development community in 1990 and triggered a range of research and development initiatives. This thesis describes the development of an inter-disciplinary diagnostic tool to assess impacts of farm management practices on soil nutrient balances and the use of the tool in participative research and innovation approaches in East Africa over a ten-year period from 1995 to 2005.

The introduction (Part 1) includes an overview of the evolution of the NUTMON approach and changes in thinking about technology development, innovation, extension and learning processes in smallholder agriculture.

In Part 2 the conceptual framework of the nutrient monitoring accounting tool (NUTMON) is presented. Chapter 1 provides a global classification of agro-ecosystems according to various degrees of soil nutrient depletion followed by a concept of related quantitative indicators. The presented research agenda at the end of the chapter is being addressed in this thesis. Chapter 2 describes the necessary disciplines and spatial scales for diagnosis, analysis and action to address soil nutrient depletion. A comparison with methodologies and approaches being used at that time, is made. Finally Chapter 3 describes the general characteristics of the NUTMON tool.

Part 3 describes the experiences and results of the implementation of NUTMON in combination with action-oriented approaches in various agro-ecological zones in Kenya and Uganda in the period 1995-2006. The role of NUTMON in a technology development process with a high degree of participation of the farmers was evaluated positively. The mix of a qualitative and quantitative diagnostic approach facilitated interactions between researchers, extension staff and farmers. Gradually a further integration of the NUTMON tool in participatory and learning processes was realised.

The various projects which implemented the approach, showed that negative soil nutrient balances and high poverty rates prevail in most of the farming systems in East Africa. A considerable proportion of the farm income was based on soil nutrient mining. However, huge variations between geographical areas and individual farms were observed. Existing variations in soil characteristics, agro-ecology, market integration and social aspects played a major role in the performance of farming systems. It was observed that cash crops realise higher gross margins and less negative nutrient balances than food crops. The type of livestock management system and the integration with the crop activities often largely

determined the nutrient balance and the options for improvements of soil fertility management systems. Nutrient-adding through combinations of organic manures and fertilizers appeared to be the most effective strategy to address negative nutrient balances. Innovations in soil fertility management were most successful and had the greatest impact on livelihoods in areas with both high agricultural potential and access to large urban markets. Investments in soil management or other technologies can be realised more easily by smallholders when they have opportunities to generate cash through commercial sales and value-addition, or when they have access to non-farm income. In semi-arid areas however most of the nutrient-adding technologies were financially unattractive or risky (Chapter 4). Only in a more favourable environment, such as areas with options of small-scale gravity irrigation, investments in soil fertility management were attractive and implemented by farmers. The technical learning and innovation processes in Farmer Field Schools (FFS) had a positive impact on the level of knowledge, skills and experimentation/innovation of the FFS members (Chapter 5). Adoption of the technologies tested by the farm households was selective, and higher if evaluated positively during experimentation on the central plot. Several nutrient-adding technologies tested in crops (manure, fertiliser, composting, Tithonia and Rhizobium) as well as modified livestock management and feeding practices were adopted by 40-70% of the farmers. As a result, farm households reported higher productivity and financial returns, while soil partial soil nutrient balances showed equal or declining nutrient depletion.

Part 4 evaluates the lessons learnt from the various field activities addressing soil fertility management and attempts to relate technology development to facilitating policies, market developments, institutional aspects and value-chain processes. It is concluded that participatory methodologies have limited impact when no attention is paid to participatory policy development and implementation. In order to mobilise farm households in a trend reversion, a number of conditions should be met such as stable prices for agricultural outputs, better input/output prices ratios, influence of land users on the research agenda and private-public initiatives focused on smallholders. This observation calls for the establishment of interactive landusers-science-policy triangles at various scales in which joint learning and mediating may lead to more informed decision making, more focused design of an agricultural sector policy, implementation of policies by effective institutions, and appropriate technology development and implementation. Interventions need to be reoriented towards policy influence and institution building.

The thesis concludes (Part 5) with evaluation of the NUTMON approach in relation to other methods and a description of the envisaged future developments. The structured conceptual framework and related NUTMON approach facilitate a comprehensive description and analysis of management practices in complex smallholder farming systems. The approach has been successfully applied in a variety of projects addressing soil fertility degradation in Africa and Asia. A wide audience from both the research and development communities have been exposed to the approach. The integration of biophysical, financial and livelihood aspects in the analyses proved essential to assist effective decision making by farm households. The quantitative analysis based on farmers' own data and observations, complements other participative tools and contributed to learning and innovation processes within households. Limitations of the approach focus on the lack of validation of the hard-to-quantify soil nutrient flows, the static nature and the difficulties in using the tool for finding solutions and assessing the impacts of innovations. Future developments focus on the role of the monitoring instrument to assist smallholder farmers in optimising farm management, sustainable use of natural resources, improve market linkages, diversify sources of income and reduce risks.

Thereafter the role of NUTMON and participatory research approaches such as Farmer Field Schools in developing effective innovation systems in smallholder agriculture and the options for implementation in Africa are discussed. The research has shown that, once smallholders are equipped with knowledge and the capacity to learn, are empowered in organizations and connected to markets and the private sector, they can substantially improve their rural livelihoods. Therefore a focus on participatory experiential learning approaches and farmer organizations that result in new arrangements in innovation systems needs to be mainstreamed in rural development projects. Experiences show that the sustainability of group learning processes increases considerably when the groups engage successfully in commercial activities at the same time.

Efforts and results from research and development organisations to improve the enabling environment have so far been very limited, but should receive priority on topics such as producers' organisations, transaction costs in agro-food chains, price and weather risks, administrative constraints, agro-food chain configurations. The need for research in technical issues (agronomy, biotechnology, soils, IPM, etc.) remains strong in order to increase the productivity and sustainability of the smallholder farming systems. But the technical research agenda needs to be imbedded in the new innovation systems to become more demand-oriented and linked to activities focusing on creating and improving a conducive environment.

Samenvatting

Behoud en verbetering van bodemvruchtbaarheid is een belangrijke strategie voor Afrika om de doelstellingen van de Millennium Ontwikkelingsdoelen (Millenium Development Goals - MDG's) te bereiken. Een vruchtbare bodem en een gebalanceerd bodem nutriënten management zijn belangrijke fundamenten voor duurzame voedselproductie, dragen bij aan een verstandig beheer van natuurlijke hulpbronnen en zijn belangrijke factoren bij het aanpakken van milieuproblemen zoals bodem erosie, verlies van biodiversiteit, water verontreiniging en bodemverzuring. Het is algemeen aanvaard dat activiteiten op het gebied van bodemvruchtbaarheid moeten worden uitgevoerd in een breder kader van armoedebestrijding met als componenten het herstel van prioriteit in nationale budgetten voor de landbouw als motor voor economische ontwikkeling, versterken van de positie van vrouwen, stimuleren van gemeenschappelijke activiteiten gericht op het verminderen van honger, verbetering van de kwaliteit van voedsel, ontwikkeling van markten en infrastructuur en het duurzaam verbeteren van het milieu. Het formele landbouwkundig onderzoek heeft veel kennis en inzichten gegenereerd in bodemvruchtbaarheid en mogelijkheden deze te verbeteren. Echter toepassing van kennis door de kleinschalige landbouwsector in Afrika is teleurstellend. Nieuwe methoden zijn nodig om kleinschalige boeren actief bij het onderzoek te betrekken, de ontwikkeling van technieken en innovaties nog meer specifiek te maken voor de verschillende fysische, klimatologische, economische en sociale omstandigheden waarin kleinschalige boeren opereren en te komen tot een integratie van technologie ontwikkeling en verbetering van het economisch klimaat voor kleinschalige boeren.

De serieuze bedreiging van het verlies van bodemnutriënten voor de duurzame productiviteit van landbouwbedrijfssystemen in Afrika werd in 1990 geagendeerd en bracht een groot aantal onderzoeksactiviteiten teweeg. Deze thesis beschrijft de ontwikkeling van een inter-disciplinair en diagnostisch model om de invloed van bedrijfsvoering op bodem nutriënten balansen te evalueren en de integratie van dit model in participatieve onderzoeksmethoden in Oost Afrika in de periode 1995 – 2005.

De inleiding (Deel 1) beschrijft een overzicht van de ontwikkelingen van het NUTMON model en de veranderende denkwijzen op het gebied van technologieontwikkeling, innovatie, voorlichting en leerprocessen in de kleinschalige landbouw.

In Deel 2 wordt het conceptuele raamwerk van het nutriënten monitoring model (NUTMON) gepresenteerd. In hoofdstuk 1 wordt een globale indeling van landbouw-klimaat-systemen gepresenteerd op basis van verschillende niveaus van bodemnutriënten degradatie en daaraan gerelateerde kwantitatieve indicatoren. De onderzoeksagenda die hierin wordt gepresenteerd vormt de leidraad voor deze thesis. Hoofdstuk 2 beschrijft de noodzakelijke expertisen en ruimtelijke schalen voor de diagnose, analyse en uitvoering van activiteiten gericht op het tegengaan van verlies van bodemnutriënten. Er wordt een vergelijking gemaakt met de op dat moment beschikbare modellen en benaderingen. Tenslotte beschrijft Hoofdstuk 3 de algemene karakteristieken van het NUTMON model.

In Deel 3 worden ervaringen en resultaten van de toepassing van het NUTMON model in combinatie met actieonderzoek in verschillende landbouw-klimaat zones in Kenia en Oeganda beschreven over de periode 1995 - 2006. De rol van het NUTMON model in processen van technologie ontwikkeling samen met boeren werd positief geëvalueerd. De mix van een kwalitatieve en kwantitatieve diagnostiek bevorderde de samenwerking tussen onderzoekers, voorlichters en boeren. Geleidelijk werd een verdere integratie van NUTMON in participatieve en leerprocessen gerealiseerd.

In de verschillende uitgevoerde projecten bleek dat negatieve nutriënten balansen en inkomens beneden de armoedegrens wijd verspreid zijn in de bedrijfssystemen in Oost Afrika. Een aanzienlijk deel van het inkomen uit de landbouw was gebaseerd op

bodemuitputting. Er bestond echter een grote variatie in de situatie tussen geografische gebieden en individuele bedrijven. Daarnaast speelden bodemkarakteristieken, ecologische omstandigheden, markt integratie en sociale aspecten een belangrijke rol op de prestatie van de landbouwsystemen. Het onderzoek gaf aan dat ‘cash crops’ in het algemeen hogere economische rendementen genereren bij minder negatieve nutriënten balansen. Het gehanteerde veehouderij systeem en het niveau van integratie met gewasproductie hadden meestal een grote invloed op de nutriënten balans en op de opties voor verbetering de bodemvruchtbaarheid. Het toevoegen van nutriënten in de vorm van combinaties van organische meststoffen en kunstmest bleek de meest effectieve strategie om negatieve nutriënten balansen aan te pakken. Innovaties in bodemvruchtbaarheid waren het meest succesvol en hadden de hoogste positieve invloed op de leefomstandigheden in gebieden met een hoog landbouwkundig potentieel en een goede toegang tot urbane markten. Het blijkt dat kleinschalige boeren gemakkelijker investeringen kunnen doen in bodemvruchtbaarheid of andere technologieën als zij mogelijkheden hebben tot cash inkomsten middels verkoop van landbouwproducten of niet-landbouw activiteiten. Echter in drogere gebieden bleken de meeste technieken om nutriënten aan het landbouwsysteem toe te voegen niet rendabel of risicovol (hoofdstuk 4). Alleen in meer gunstige omstandigheden, zoals gebieden met mogelijkheden tot kleinschalige irrigatie, bleken investeringen in bodemvruchtbaarheid rendabel en werden ook daadwerkelijk door boeren toegepast. De toegepaste leer- en innovatie processen in ‘Farmer Field Schools’ hadden een positieve invloed op het kennisniveau, vaardigheden en het uitvoeren van experimenten van de leden van de scholen (hoofdstuk 5). Adoptie van de geteste technologieën door de boeren was selectief, maar relatief hoog indien een positieve invloed op de productiviteit was geconstateerd tijdens het proces van experimenteren. Verschillende technieken in gewassen (organische mest, kunstmest, composteren, Tithonia en Rhizobium) en veranderingen in het veehouderijmanagement en voeding werden geadopteerd door 40-70% van de boeren. Als gevolg hiervan rapporteerden de meeste boeren een hogere productiviteit, betere financiële resultaten bij gelijkblijvende of afnemende verliezen aan bodemnutriënten.

Deel 4 evalueert de lessen van de verschillende activiteiten en probeert de ontwikkeling van technologie te relateren aan benodigd beleid, marktontwikkelingen, institutionele aspecten en voedselketens. Er wordt geconcludeerd dat het bevorderen van participatieve methoden weinig impact hebben als deze niet samengaan met participatieve beleidsontwikkeling en uitvoering. Om boeren te mobiliseren tot een trend wijziging moet aan verschillende voorwaarden worden voldaan zoals stabiele prijzen voor landbouwproducten, betere input/output prijsverhoudingen, invloed van landgebruikers op de onderzoeksagenda en privaatpublieke initiatieven gericht op kleinschalige boeren. Deze constatering vraagt om het oprichten van interactieve fora van landgebruikers, onderzoekers en beleidsmakers gericht op gezamenlijk leren en onderhandelen met als uiteindelijk doel te komen tot beter geïnformeerde besluitvorming, formulering van doelgerichte landbouwsector beleid, effectieve uitvoering van beleid door instituties en ontwikkeling en toepassing van aangepaste technologieën. In het algemeen behoeven interventies een heroriëntatie met grotere aandacht voor beleidsvorming en opbouw van instituties.

De thesis eindigt in Deel 5 met een evaluatie van het NUTMON model ten opzichte van andere methoden en een beschrijving van de voorziene toekomstige ontwikkelingen. Het gestructureerde en conceptuele raamwerk en het daaraan gerelateerde NUTMON model helpen om te komen tot een volledige beschrijving en analyse van bedrijfsvoering van complexe kleinschalige landbouwbedrijven. Deze benadering is met succes toegepast in projecten rond het aanpakken van bodemdegradatie in Afrika en Azië en heeft grote belangstelling getrokken van onderzoekers en de ontwikkelingsdeskundigen. De integratie van biofysische, financiële en ‘livelihood’ aspecten in deze benadering is essentieel om de besluitvorming op het niveau van boerenhuishoudens effectief te kunnen ondersteunen. De kwantitatieve analyse grotendeels gebaseerd op gegevens en observaties van de boeren zelf, vormt een belangrijke aanvulling op de bestaande participatieve methoden en draagt bij aan het leer en innovatieproces op huishoudniveau. De beperkingen van NUTMON liggen bij het gebrek aan validering van de de ‘moeilijk-te-kwantificeren’ nutriënten stromen, het statische karakter van het model en de moeilijkheden in het gebruik van dit instrument bij het vinden en evalueren van nieuwe technische oplossingen. Toekomstige ontwikkelingen van het model richten zich op de rol van monitoring instrumenten bij het ondersteunen van kleinschalige boeren in het optimaliseren van de bedrijfsvoering, het duurzaam gebruik van natuurlijke hulpbronnen, het verbeteren van toegang tot markten, diversificatie van inkomensbronnen en het reduceren van risico’s.

Hierna volgt een discussie over de rol van NUTMON in participatieve onderzoeksbenaderingen, zoals Farmer Field Schools, in het ontwikkelen van innovatiesystemen gericht op de kleinschalige landbouw en de opties voor de implementatie ervan in Afrika. Het onderzoek heeft aangetoond dat wanneer boeren eenmaal zijn uitgerust met kennis, capaciteiten om te leren zijn versterkt, georganiseerd zijn en toegang tot markten en private sector hebben, zij zelf in staat zijn substantiële verbeteringen in hun leefomstandigheden te kunnen realiseren. Het is daarom van belang dat participatieve leerprocessen en nieuwe arrangementen in innovatiesystemen op grote schaal worden toegepast in plattelandsontwikkeling. De ervaringen in dit onderzoek laten zien dat de duurzaamheid van leerprocessen in groepen drastisch toeneemt wanneer deze tevens succesvol actief zijn in commerciële activiteiten.

Onderzoek- en ontwikkelingsorganisaties hebben tot op heden slecht mondjesmaat aandacht besteed aan het verbeteren van de omgevingsfactoren voor kleinschalige landbouw. Er is daarbij behoefte aan activiteiten op het gebied van producenten organisaties, transactiekosten in voedselketens, prijs en weer risico’s, administratieve barrières en nieuwe configuraties in de voedselketen. Er blijft evenwel behoefte aan technologisch onderzoek met als doel de productiviteit en duurzaamheid van de kleinschalige landbouw in Afrika te vergroten. Echter de technische onderzoeksagenda moet beter worden verankerd in nieuwe innovatiesystemen om te komen tot een betere vraaggestuurde agenda en integratie met de verbetering van andere gerelateerde omgevingsfactoren.

CURRICULUM VITAE

Adriaan de Jager was born on January 1st, 1958 in Nieuw- en Sint Joosland, Province of Zeeland in The Netherlands. During his youth he gained practical farming experience on the family fruit farm. He studied at Wageningen University from 1976 to 1983 and obtained a M.Sc. degree in Horticulture with a major in Economics. From 1983 to 1988 he worked as Project Manager of an ICCO-financed rural development project focusing on applied agricultural research and extension in northern Ghana. In 1988 he joined the Agricultural Economics Research Institute (LEI-DLO) where he held various positions. He started as researcher, focusing on the Dutch Horticultural sector, switching a few years later to technical and economic aspects of farming systems research in international development-oriented research programmes. In the period 1991-1992 he was based in Indonesia and responsible for the On-Farm-Client-Oriented Research Programme in a Indonesian-Dutch bilateral research project to develop the Indonesian vegetable sector. He acquired and managed various major long-term inter-disciplinary research programmes and projects funded by the EU and the Dutch Ministries of Foreign Affairs (DGIS) and Agriculture, Nature and Food Quality (LNV) on topics such as ‘sustainable food security in West Africa’, ‘development of sustainable agriculture in India’, ‘socio-economic aspects of horticulture development in Fayoum Egypt’ and ‘development of peri-urban agriculture in Asia and West Africa’. During this period he participated in an inter-disciplinary research team that initiated a long-term research programme on Integrated Nutrient Management in Africa. In that framework he acquired and managed two EU-funded long-term research and development projects in the period 1996 to 2005 in Kenya, Uganda and Ethiopia implemented by inter-disciplinary African-Dutch teams of researchers and NGO-staff. In these projects he contributed to the development of the nutrient monitoring model (NUTMON) and initiated the integration of NUTMON in participatory research approaches and Farmers Field Schools. Thereafter he focused on developing international public-private partnerships on high-value crops and research on horticultural chains for the domestic as for the international market. Activities included the coordination of the following projects: ‘facilitating public-private partnerships in the horticultural sector to improve market access in East Africa’, ‘impacts of EU regulations on maximum residue limits (MRL’s) of pesticides on African horticulture sector development’ and ‘set-up of a sustainable tea supply chain with smallholder farmers in Kenya’. In this period he conducted short-term research and consultancy assignments and participated in international symposia in Ethiopia, Egypt, South Africa, Burkina Faso, Tanzania, India, Rwanda, USA, Zambia, Vietnam, Thailand, Mali, Japan, Benin, Togo, China, Brazil, Uruguay, Argentina, and Taiwan.

More recently he engaged in research management activities after having completed a management training at De Baak. He contributed to the establishment of, and participated in the implementation of the front-office of Wageningen International. In the period 2000 to 2006 he managed the DLO research and capacity building programme on international cooperation financed by LNV with an average annual research budget of € 7 million. In 2006 he was heading the division trade and development at LEI. At the end of 2007 he will be heading the division markets and networks at LEI.

List of Major Publications

Scientific Journal Articles

De Jager, A., van Keulen, H., Mainah, F., Gachimbi, L.N., Itabari, J.K., Thuranira, E.G., Karuku, A.M., 2006. Attaining sustainable farm management systems in semi-arid areas in Kenya: few technical options, many policy challenges. International Journal for Sustainable Agriculture 3 (3): 189-205.

Onduru, D.D**., De Jager, A**., and Gachini, G.N., 2006. The hidden costs of soil mining to agricultural sustainability in developing countries. International Journal for Sustainable Agriculture 3 (3): 167–175.

De Jager, A., 2005. Participatory technology, policy and institutional development to address soil fertility degradation in Africa. Land Use Policy 22: 57-66.

Muchena, F.N., Onduru, D.D. and **De Jager, A.**, 2005. Turning the tides of soil degradation in Africa: capturing the reality and exploring opportunities. Land Use Policy 22: 23-31.

Gachimbi, L.N, Van Keulen, H., Thuranira, E.G., Karuku, A.M., **De Jager, A**., Ngulu, S., Ikombo, B.M., Kinama, J.M., Itabari, J.K., Nandwa, S.M., 2005. Nutrient balances at farm level in Machakos (Kenya), using a participatory nutrient monitoring (NUTMON) approach. Land Use Policy 22: 13-22.

De Jager, A., Onduru, D.D., Walaga, C., 2004. Facilitated learning in soil fertility management: assessing potentials of low-external-input technologies. Agricultural Systems Vol. 79: 205-223.

Onduru, D.D., Diop, J.M., Van der Werf, E., and **De Jager, A**., 2002. Participatory on-farm comparative assessment of organic and conventional farmers' practices in Kenya. Biological Agriculture and Horticulture 19: 295-314.

De Jager, A., Onduru, D., Van Wijk, M.S., Vlaming, J. and Gachini, G.N., 2001. Assessing sustainability of low-external-input farm management systems with the nutrient monitoring approach: a case study in Kenya. Agricultural Systems 69: 99-118.

De Jager, A., Nandwa, S.M. and Okoth, P.F., 1998. Monitoring nutrient flows and economic performance in African farming systems (NUTMON). I. Conceptual framework. Agriculture, Ecosystems and Environment 71: 37-48.

De Jager, A., Kariuki, F.M., Matiri, M., Odendo and Wanyama, J.M., 1998. Monitoring nutrient flows and economic performance in African farming systems (NUTMON). IV. Monitoring of farm economic performance in three districts in Kenya. Agriculture, Ecosystems and Environment Vol 71: 81-92.

Bosch, H. van den, **De Jager, A**. and Vlaming, J., 1998. Monitoring nutrient flows and economic performance in African farming systems (NUTMON). II. Tool development. Agriculture, Ecosystems and Environment 71: 49-62.

Smaling, E.M.A., L.O.Fresco and **De Jager A**., 1996. Classifying, monitoring and improving soil nutrient stocks and flows in African agriculture, Ambio vol.25 (8): 492-496.

Books/Chapters in books

Sonko, R., Njue, E., Ssebuliba, J.M. and **De Jager, A.**, 2005. The Horticultural sector in Uganda. Scripta Horticulturae 1, International Society for Horticultural Science, Leuven, Belgium.

De Jager, A., Onduru, D. and Walaga, C., 2003. Using NUTMON to evaluate conventional and low-external input farming practices in Kenya and Uganda. In: Struif Bontkes, T.E. and Wopereis, M.C.S. (Eds.) Decision support tools for smallholder agriculture in Sub-Saharan Africa: a practical guide, IFDC/CTA, Muscle Shoals (USA) / Wageningen (The Netherlands).

Gachimbi, L.N., **De Jager, A.**, Van Keulen, H., Thuranira, E.G., Nandwa, S.M., 2002. Participatory diagnosis of soil nutrient depletion in semi-arid areas of Kenya. Managing Africa's Soil No.26, IIED, UK.

Onduru, D.D., **De Jager, A.**, Gachini, G. and Diop, J.M., 2001. Exploring new pathways for innovative soil fertility management in Kenya. Managing Africa's Soils No. 25, IIED, UK.

Van den Bosch, H., Eaton, D., Van Wijk, M.S., Vlaming, J., **De Jager, A.**, 2001. Monitoring nutrient flows and economic performance in African farming systems: The NUTMON approach and its applicability to peri-urban agriculture. In: Drechsel, P. and Kunze, D. (Eds.) Waste Composting for Urban and Peri-Urban Agriculture: Closing the Rural – Urban Nutrient Cycle in Sub-Saharan Africa, CABI.

Smaling, E.M.A., Stoorvogel, J.J**., De Jager, A.**, 2001. Decision making on integrated nutrient management through the eyes of the scientist, the land user and the policy maker. In: Van Lauwe, B. et al. (Eds.) Integrated Plant Nutrient Management in Sub-Saharan Africa, CABI.

Hilhorst, T., Muchena, F., Defoer,T., Hassink, J., **De Jager, A.,** Smaling, E.M.A. and Toulmin, C., 2000. Changing soil fertility management practices in Africa. In: T. Hilhorst and F. Muchena (Eds.) Nutrients on the move, IIED, UK.

Onduru, D.D., Gachini, G., **De Jager, A.**, and Diop, J.M., 1999. Participatory research of compost and liquid manure in Kenya. Managing Africa's Soils No.8, IIED, UK.

De Jager, A., Smaling, E.M.A., Onduru, D., Bekunda, M., Roling, N.G.,1999. Designing Integrated Nutrient Management Systems in sub-Saharan Africa. In: Leeuwis, C. (Ed.) Integral design: innovation in agriculture and resource management, Wageniningen University, Mansholt Studies 15, Wageningen, The Netherlands.

De Jager, A., Mokwunye, A.U. and Smaling, E.M.A., 1998. Do fertilizers play a major role in sustainable agricultural development in West Africa? In: Wossink, G.A.A., Van Kooten, G.C. and Peters, G.H. (eds) Economics of agro-chemicals; an international overview of use patterns, technical and institutional determinants, policies and perspectives, Ashgate, England.

Al-Hassan, R., J.A. Famiyeh and **De Jager A.**, 1997. Farm household strategies for food security in Northern Ghana: a comparative analysis of high and low population farming systems. In: Asenso-Okyere, W.K., G. Benneh and W. Tims (eds.) Sustainable food security in West Africa, Kluwer Academic Publishers.

Mokwunye A.U., **De Jager, A.**, and Smaling, E.M.A., 1995. Restoring and Maintaining the productivity of West African soils: key to sustainable development, IFDC miscellaneous studies no. 9, Lome, Togo.

De Jager, A. and Van der Werf, E., 1993. Economic and ecological potentials of sustainable agriculture in South-India, In: Plant production on the threshold of a new century; proceedings of the International Conference on the Occasion of the 75th anniversary of the Wageningen Agricultural University, Wageningen.

De Jager A., 1991. Towards self-experimenting village groups, In: Joining Farmers' Experiments, Experiences in Participatory Technology Development, Intermediate Technology Publications.

De Jager A. and A.P. Verhaegh (eds.), 1989. First International Symposium on Horticultural Economics in Developing Countries. ISHS Acta Horticulturae 270.

PE&RC PhD Education Certificate

With the educational activities listed below the PhD candidate has complied with the educational requirements set by the C.T. de Wit Graduate School for Production Ecology and Resource Conservation (PE&RC) which comprises of a minimum total of 32 ECTS (= 22 weeks of activities)

Review of Literature (5.6 credits)

- For the published articles in the thesis, the introduction and the concluding chapter a thorough review of literature was conducted (1998-2007)

Writing of Project Proposal (7 credits)

- The majority of the research described in this thesis is based on three long-term projects financed by the European Union. As project coordinator, the candidate took the lead in the formulation of all the three proposals:
  Potentials of low-external input and sustainable agriculture (LEISA) to attain productive and sustainable land use in Kenya and Uganda (LEINUTS) to EU DG-research (1995)
  Assessment and monitoring of nutrient flows and stocks in ASAL (NUTSAL) to EU (1998)
  Integrated nutrient management to attain sustainable productivity increases in East African farming systems (INMASP) to EU-DG research (2000)

Laboratory Training and Working Visits (5.6 credits)

- NUTMON application in Indonesia (1 week); CARE-Indonesia (2002)
- Natural resources management South Africa (1 week); ARC-Pretoria (2005)
- Farmer fields schools in vegetable production (1 week) PROTA/ICRAF (2005)
- Farmer field schools in sustainable tea production in Kericho Kenya (1 week) Lipton/KTDA (2006)

Post-Graduate Courses (2.8 credits)

- Trade-off analysis training Nairobi (1 week); ILRI/WUR (2004)
- Innovation Africa workshop Kampala (! Week; oral presentation); CIAT (2006)

Competence Strengthening / Skills Courses (8.4 credits)

- Management course 'the new manager' (6 weeks); De Baak (2002-2003)

Discussion Groups / Local Seminars and Other Scientific Meetings (25.8 credits)

- Monthly section meetings at LEI with thematic discussions and discussion on research projects, MSc and PhD projects (6 days per year for 6 years) (2000-2007)
- Attended and organized approximately 10 local seminars in Kenya, Uganda and Ethiopia in framework of ongoing projects LEINUTS, NUTSAL and INMASP (estimated time 50 days) (2000-2006)

PE&RC Annual Meetings, Seminars and the PE&RC Weekend (2.1 credits)

- Organised local seminar at Wageningen UR on NUTMON experiences (2 days) (2001)
- Expert meeting wereldvoedseldag, Wageningen (2006)
- Discussion meetings LNV-WUR on sustainable agriculture, Wageningen (2005)
- Participation/presentations North-South platform meetings, Wageningen (2005)
- Discussion in public debate smallholder farming in Africa, Wageningen/Amsterdam (2005)

International Symposia, Workshops and Conferences (15.2 credits)

- FFS Experiences 'workshop on local land and water management in Africa Jinja, Uganda; FAO-CTA (1 week, oral presentation) (2006)
- International soil workshop Nairobi Kenya Rockefeller Foundation (1 week, oral presentation) (2004)
- Information support systems symposium; Florida, USA (1 week, oral presentation) (2002)
- Meeting global horticultural initiative; Montpellier (2006)
- Meeting global horticultural initiative; Arusha (2005)
- Meetings team LNV cluster international; Wageningen (2005)
- EU consultation on pro-poor horticulture project; Brussels (2005)