Soil Fertility Evaluation and Management by Smallholder Farmer Communities in Northern Tanzania[1]

Jeremias G. Mowo[1,2], Bert H. Janssen[3,4], Oene Oenema[5], Laura, A. German[6]
Jerome P. Mrema[7] and Riziki S. Shemdoe[7]

[1]Directorate of Research and Development, Box 5088, Tanga, Tanzania
[2]Institut des Sciences Agronomiques du Rwanda (ISAR), Box 138, Butare, Rwanda
[3]Wageningen University, Department of Soil Quality, Box 8005, 6700 EC, Wageningen, The Netherlands
[4]Wageningen University, Plant Production Systems Group, Box 430, 6700 AK, Wageningen, The Netherlands
[5]African Highlands Initiative, Box 26416 Kampala Uganda
[6]Sokoine University of Agriculture, Box 3000, Morogoro, Tanzania
[7]University of Dar es Salaam, Box 31576, Dar es Salaam, Tanzania

Abstract

The role of the smallholder farmer community in soil fertility evaluation and management was examined from two 'research for development' projects in northern Tanzania. These are the African Highlands Initiative (AHI) and the Soil Water Management Research Group (SWMRG). Participatory approaches were applied by both projects. Farmers' knowledge and experience were used in identifying soil fertility constraints using local indicators of soil quality and in generating resource flow maps. The farmers' evaluation of soil fertility was compared with soil analytical data and with calculations of maize yields by the model QUEFTS. The use of farmers' indigenous knowledge in soil fertility evaluation mostly agreed with laboratory analysis and model calculations by QUEFTS. Model calculations identified potassium as the most limiting nutrient in the highlands for yields less than 3 t ha^{-1} and phosphorus for yields higher than 4 t ha^{-1}. Given that farmers' evaluation of soil fertility is relative to what they see around them, there is a need to verify their observations, but also the interpretation of laboratory data by models like QUEFTS requires continuous and critical validation. Both projects have shown that there is scope to reverse the trends of declining soil fertility in smallholder farms in northern Tanzania.

Keywords: Farmer decision environment, Farmer empowerment, Local indicators, Organic nutrient resources, Participatory approaches, QUEFTS, Soil fertility evaluation, Smallholder farmers

Introduction

Sustained agricultural production in most Sub-Saharan countries is under threat due to declining soil fertility and loss of topsoil through erosion (Hellin, 2003; Sanchez, 2002). The smallholder farmers in these countries are quite aware of the declining trends in soil fertility, the reasons for this and its impact on yields and household food security (Lyamchai and Mowo, 2000; Defoer and Budelman, 2000; Ouédraogo, 2004; Saïdou et al., 2004). Many farmers also do know to some extent how to practice judicious management of their soils, using nutrients available in their vicinity and adopting agricultural practices geared towards soil fertility improvement such as improved fallow, agroforestry and biomass transfer (Wickama and Mowo, 2001; Johansson, 2001; Rwehumbiza et al., 2003). On the other hand, the many endogenous and exogenous complicating factors (Van der Ploeg, 1993; Ondersteijn et al., 2003), most of which are beyond the smallholder capability to handle, account for the continual trends in soil fertility decline. Admittedly, soil fertility management is highly complex given the myriad of interacting factors that dictate the extent to which farming households invest in the fertility of their soils. These interacting factors must be understood, as judicious soil fertility management is of vital importance for sustaining food production in smallholder communities.
The complexity of soil fertility management in smallholder farms calls for active participation of farmers and other stakeholders. Consequently, two projects in Tanzania; the African Highlands Initiative (AHI) and the Soil Water Management Research Group (SWMRG) have adopted multi-stakeholder, multi-institutional and

---

[1] Article in press: Mowo, J.G., B.H. Janssen, O. Oenema, L. German, J.P. Mrema and R.S. Shemdoe (in press), *Agriculture, Ecosystems and Environment*.

participatory approaches to soil fertility management with emphasis on interdisciplinary teamwork, to share and exploit expertise from different professionals and institutions (Mowo et al., 2004; SWMRG, 2002). The premise of the projects is that the wealth of indigenous knowledge coupled with the farmers comparative advantage of being familiar with their own environment should be exploited for better management of soil fertility for improved system productivity.

In this paper, we discuss the role of smallholder farmer communities in soil fertility evaluation and management based on results and experiences from these two 'research for development' projects in Tanzania. Research questions addressed in the projects include (i) What approaches are in place for enabling farmers to effectively manage soil fertility? (ii) How is farmer's indigenous knowledge applied to evaluate soil fertility and take decisions on nutrient management? (iii) Is it possible to translate farmers' knowledge and information into formal knowledge? (iv) Why are some farmers better soil fertility managers than others? (v) Which questions require concerted action of farmers' communities rather than individual activities? (vi) Which factors influence farmer ability to invest in soil fertility management? (vii) How does soil fertility management affect sustainability of the physical environment?

The paper starts with our conceptual framework on the role of the farmer in soil fertility and nutrient management. Next, the approaches, activities and results of AHI and SWMRG are considered in relation to the conceptual framework. A major part of the paper deals with the comparison of farmers' evaluation of soil fertility with soil analytical data and related yields as calculated with the model QUEFTS (Quantitative Evaluation of the Fertility of Tropical Soils. A sequence of steps is proposed including efficient use of available nutrient resources, improving farmers' access to information and links with markets to gradually enable farmers to enter into the market economy which might stimulate investment in soil fertility management. Finally suggestions are made for addressing research gaps.

CONCEPTUAL FRAMEWORK ON DECISION MAKING IN SOIL FERTILITY MANAGEMENT BY FARMERS

Farming in a Dynamic Environment

Soil fertility and nutrient management are functions of socio – economic processes associated with a household and its management. To understand the farmer's role in soil fertility and nutrient management we need to know who the farmer is and what factors are influencing his decision making. It is Phase 1 in a Participatory Learning and Action Research (PLAR) process (Defoer, 2002). Smallholder farms usually consist of small parcels of land. A farmer, also the smallholder, has triple functions as entrepreneur, manager and craftsman (laborer) (Figure 1). As entrepreneur the farmer defines the mission and long-term objectives of the farm and devises strategies to realize set objectives. As manager the farmer allocate resources to achieve the objectives. In principle, he or she makes an analysis of all farm operations, decides what to do, and plans, executes and controls the things that have to be done. As craftsman, the farmer needs the technical skills and capabilities to carry out required activities for optimal performance of the farm. Several of the activities covered by the two projects in this study such as the PRA, training and farmer tours contributes to empowering the farmer as an entrepreneur, a manager and a craftsman.

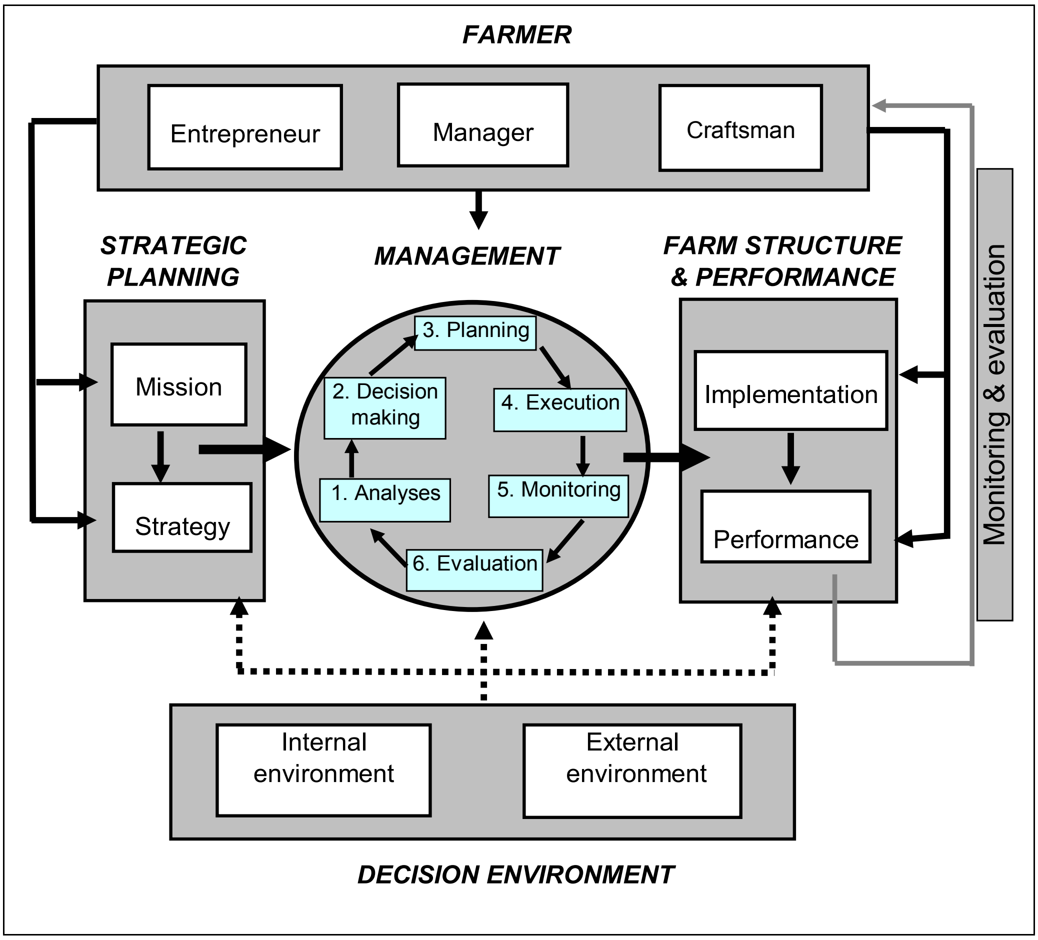

Figure 1. Operation of a smallholders' farm. Modified after David (2001) and Ondersteijn et al. (2003)

Decision-Making Process at Farm Level

Differences in performance between farms and in the way farmers respond to for example changes in markets, governmental policies, soil fertility and weather can be explained by the fact that not all farmers are equally skilful as entrepreneur, manager and craftsman. Further, the extent of and capability to sustain what Bebbington (1999) refers to as the five capital assets available to rural communities, that is human, physical, natural, social and financial capitals, differ among farmers. In Figure 2, a range of dominant driving forces for the decision making process at farm level is depicted.

general, farmers have various objectives, which they try to realize as best as possible. Some objectives are common, like sufficient income (financial capital) and continuity of the farm (natural capital), while others are more specific, related to the drives, conviction and style of the farmer. Decisions about the objectives are influenced by the drives and skill of the farmer (human capital), the internal (farm) environment and the external (social, political, technological and economic) environment. The external environment is becoming increasingly important (Keeney, 1997; Bontems and Thomas, 2000). This is because of an increasing number of actors and an increasing pressure by different groups such as environmentalists and consumers to change production processes into environmentally friendly, socially acceptable and economically viable ways. The decision making process itself is governed by a complex framework of comparisons (Gomez-Limon et al. 2000).. Some farmers are led by tradition while others are influenced by what is usual at the time. The presence and cost of alternatives also influence decisions by farmers. Identifying different styles of farming may help in understanding the decision making process and in the selection of proper tools for soil fertility and nutrient management. Selection of skilful retailers and transparent markets (physical capital), and knowledge of marketing techniques are expected to improve income, which in turn might stimulate investment in soil fertility management (Whiteside, 1996.) Informal networks (social capital in the terminology of Bebbington, 1998, 1999) such as influential members of the community, clan elders and collective action groups and age mates also play a vital role in influencing farmers' ability to access sources of information and willingness to invest in soil fertility management technologies (Mowo et al., 2004; German et al. in press) and determine to a great extent whether collective actions will be successful or not.

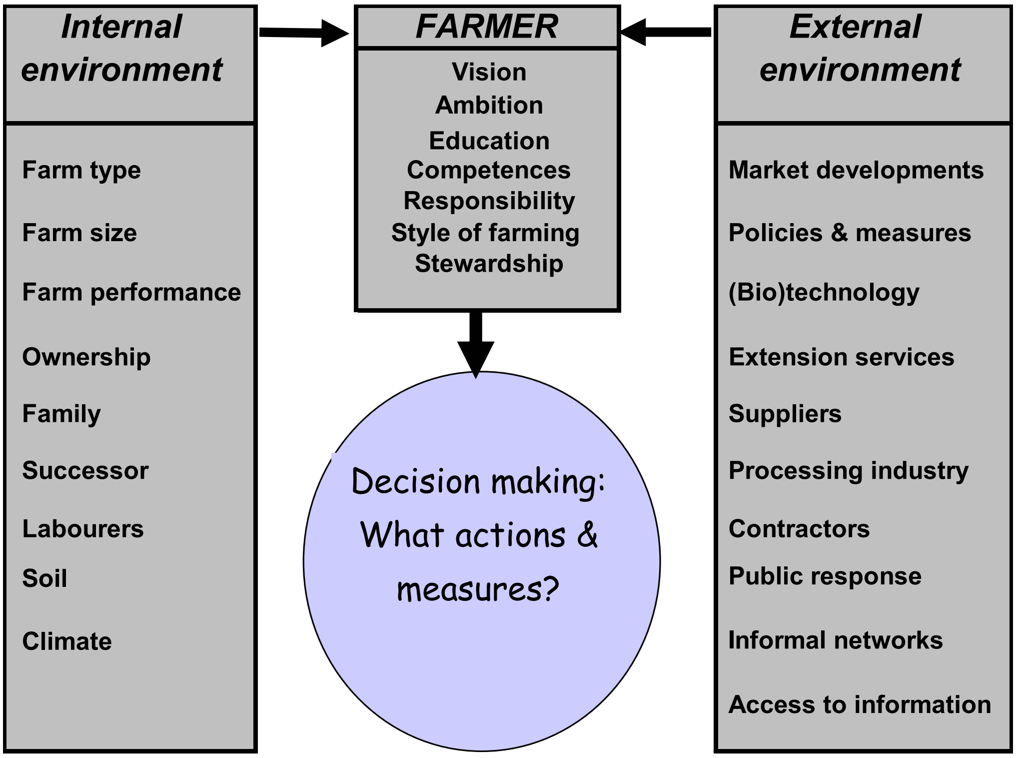

Figure 2. Conceptualization of the decision making process at farm level, showing the external and internal driving forces and the farmers' own drives (based on Van der Ploeg, 1993 and Ondersteijn et al., 2003).

APPROACH AND ACTIVITIES OF AHI AND SWMRG: METHODS OF SOIL FERTILITY EVALUATION

About the Projects

AHI is a regional program concerned with integrated natural resource management (INRM) research in the humid highlands ecosystem of Eastern Africa while SWMRG is dealing with nutrient management under rainwater harvesting systems in the dry lowlands of Tanzania. The AHI benchmark site is Lushoto District in northeastern Tanzania and the SWMRG is working in Same (Western Pare Lowlands (WPLL) in north eastern Tanzania) and Maswa (Lake Victoria basin) districts. Campbell et al. (2001) define INRM as a process of incorporating the multiple aspects of natural resource use (biophysical, socio-political, or economic) into a system of sustainable management to meet production goals of producers and other direct users (e.g., food security, profitability, risk aversion) as well as goals of the wider community (e.g., poverty alleviation, welfare of future generations, environmental conservation). INRM research approach aims at identifying land-use practices that increase production while maintaining natural capital and continuing to provide ecosystem services at local and global scales (Izac and Sanchez, 2001).

A Participatory Rural Appraisal (PRA) was conducted to analyze the situation at farm level specifically identifying constraints limiting agricultural production. Farmers were exposed to different methods of priority setting including matrix and pair-wise ranking to determine the most pressing constraints that need immediate attention. Special emphasis was given on identifying communal goals requiring joint activities of the neighborhood. Community action plans (CAP) for orderly execution of set priorities were prepared by farmers in collaboration with researchers. For quality control participatory monitoring and evaluation was adopted to monitor and evaluate the implementation of the CAP

To improve access to information which is one of the factors in the external environment (Figure 2), training and study tours were organized for farmers (Table 1) and simple reading materials were put at their disposal, like leaflets and pamphlets written in Kiswahili, the common language in the country. The design of the reading materials was based on one topic for each leaflet or pamphlet. These approaches also contributed to enabling farmers to set out realistic objectives and devising appropriate strategies, and thus challenged their entrepreneurship. This was established through focus group discussion where farmers were asked to indicate with reasons, the technologies they have adopted and any modification they have made on them as a result of the different exposures they had (German et al., in press).

Table 1. Courses and study tours organized by AHI[a] and SWMRG[b].

No	Course / Tour	Participants	Project	Course / Tour objective
1	Soil water conservation (SWC)	45	AHI	Empower local communities in establishing SWC structures.
2	Composting	65	AHI	Improve quality of, and provide alternative organic nutrient sources
3	Local indicators of soil fertility*	95	SWMRG	Create local capacity in soil fertility assessment.
4	Marketing and enterprise selection	40	AHI	Improve farmers marketing skills and selection of enterprises in reaction to market demands.
5	Tour to markets in large cities	40	AHI/Farm Africa	Enable farmers establish contacts with potential clients.
6	Tour to Kenya	10	AHI	Exchange experience in SWC and in crop and livestock husbandry.
7	Tour to Lushoto, Kilimanjaro and Arusha	46	AHI	-do-
8	Tour to Tabora and Same	15	SWMRG	Exchange experience in nutrient management under rainwater harvesting system.

[a]AHI: African Highlands Initiative
[b]SWMRG: Soil Water Management Research Group

Examining Farm Internal Environment

Various assessments were performed to identify constraints limiting agricultural production. Local indicators (Barrios et al., 2001) were used in the participatory assessment of soil quality (an internal environment factor) while participatory soil fertility and resource flow mapping were used to assess nutrient flows (de Jager et al., 2001; Defoer, 2002). Transect walks (Lightfoot, et al., 1992) were carried out to ground truth farmers' observations while laboratory analysis of selected soil samples was done to further verify farmers observations. In the AHI project, farmers were categorized into three wealth categories (rich, intermediate and poor based on indicators of resource endowment established by the farmers themselves and agreed upon by consensus. These include farm size (an internal environment factor, Figure 2), type of house whether of mud, burnt or concrete bricks and whether grass thatched or iron roofed. The proportions of farmers in each category were 5, 50 and 55 % for rich, intermediate and poor respectively. Farmers were then requested to draw resource flow maps showing the flow of resources within the farm and between farm and suppliers, retailers and markets (NR1, 2000). A time scale of one year was used. The yield and destination of the previous year crop, crop residue and livestock produce were estimated and added into the map. Farmers identified and estimated the use of fertilizers on different fields.

In the SWMRG project, farmers were categorized on the basis of gender, wealth, location of their farms in the landscape and type of enterprise. Local indicators of soil quality were used to assess the fertility of soils in three villages each in Same and Maswa districts. The villages represented upper, mid and lower slope positions. Farmers classified soil fertility as good (fertile) or bad (infertile) with respect to crop growth (suitability classes). Each farmer category roughly sketched soil fertility maps of their villages. Outcomes of observations during transect walks were compared with the results of soil analyses.

Examining Farm External Environment

To advance the knowledge about the demands and characteristics of markets, tours were organized providing farmers from different categories (gender, wealth and location) the opportunity to interact with suppliers, retailers in different markets and owners of big hotels (Table 1). Targeting big hotels was mainly confined to Lushoto farmers producing specialized fruits and vegetables not commonly consumed by the local population. These tours were followed up by a course on marketing to impart the necessary skills on enterprise selection and marketing techniques including formation of farmers marketing groups.

Different groups of farmers were interviewed using a structured questionnaire to identify policies related to soil fertility management, their adequacy and factors influencing their enforcement. Policies are an important external environment factor influencing soil fertility management. Interviewees were classified into three groups. These were 'all farmers group' made up of a sample from the village list and representing the categories gender, wealth and location in the landscape, 'leaders group' made up of local government and religious leaders and 'influential peoples group' made up of men and women who are highly respected by the community for example traditional healers, elders and retired civil servants. The different groups answered questions on how policies were formulated, who were involved and to what extent farmers were aware of these policies. Interviewees were also asked to list the local institutions and farmer networks including informal networks (Figure 2) relevant to soil fertility management, their potential and weaknesses and the ways they can be exploited in soil fertility management. Other questions focused on traditional beliefs to understand how they influence technologies uptake.

To address another important external environment factor namely technologies three on farm trials managed by farmers and based on farmers' identified soil fertility management options were conducted in order to fine-tune technologies developed in research centers to the farmers' conditions. These were (i) Enhancing the effectiveness of Minjingu phosphate rock (MPR) using organic nutrient sources (ii) the use of multipurpose leguminous trees and forage species for soil conservation, soil fertility improvement and provision of fodder and (iii) the role of improved fallow in soil fertility management. Trials were conducted for two seasons from 1999 to 2000. In this paper only the first trial is considered in detail for which the experimental design was complete randomized with four treatments (farmers practice as control, MPR applied alone, MPR + farmyard manure (FYM) and MPR + *Vernonia subligera* green manure). The role of farmers was to provide land and labor and with the help of the extension partners to evaluate the different treatments and collecting data. Researchers took a leading role in designing and monitoring the trials and in data analysis, report writing and feedback to farmers.

Soil Analysis and QUEFTS Calculations

In both projects composite soil samples (0 – 20 cm) were taken from farmers fields representing the upper, middle and low slope positions and analyzed at the National Soil Service in Mlingano for soils from the AHI project and at Sokoine University in Morogoro for soils from the SWMRG project. The methods are described by NSS (1990) and Okalebo et al. (1993), respectively. The model QUEFTS (Janssen et al., 1990) was run to evaluate the soil data. The model uses soil organic carbon and nitrogen (SOC, SON), P-Olsen, exchangeable K, and pH (H_2O) to calculate the uptake of N, P and K by a maize crop. Next, it expresses soil fertility in one parameter being estimated maize grain yield on unfertilized soil.

In the present study P-Bray-I has been used as soil P indicator, and not P-Olsen. Mowo (2000) found that P-Olsen may vary between 0.5 and 5 times P-Olsen, but mostly is between 0.75 and 2.5 times P-Bray. The results of Menon et al. (1990) are also within these boundaries. Therefore we have made the QUEFTS calculations twice assuming P-Olsen/ P-Bray-1 ratios of 0.75 or 2.5. Application of QUEFTS to the four Maswa soils with pH above 7 was too risky because the original QUEFTS has not been tested on soils with pH above 7.0. The version of QUEFTS modified by Smaling and Janssen (1993) included soils with pH up to 8, but that version asks for some parameters that had not been analyzed by SWMRG (2003).

Results

FARM INTERNAL ENVIRONMENT

Farm Characteristics and Resource Flow Maps

In Kwalei (AHI Project), there was a consistent relationship between wealth category, age and farm size (Table 2). The rich farmers, who are also the older members of the community, own significantly larger chunks of land than the other categories. They also have proportionately less land away from their homestead (23 %) compared to the intermediate (240 %) and poor (300 %) categories.

Table 2. Characteristics of farmers and farms in Kwalei village, AHI benchmark site (110 households)

Wealth category of farmers	Rich (n = 5)	Intermediate (n = 50)	Poor (n = 55)
Farmer characteristics	Hard working	Active in development	Limited participation in development projects
Training	Copy and learn from others	Received some training in soil fertility management	
Age	> 50	35 - 40	25 - 35
Farm size (ha)			
Homestead	12	1	0.4
Away	2.8	2.4	1.2
Food self sufficiency	Yes	Not	Not
Number of enterprises			
Crops	12	12	7
Cattle	5	6	2
Nutrients input	Nil, rely on tight nutrient cycling	10 kg NPK or urea, manure and fodder from neighbors	Small amounts of NPK on high value crops
Nutrients output	Coffee, tea, wood	Potato, tomato, sugar cane	Vegetables, coffee, wood

Generally resource flows within and between farmers are complex, partly because farmers have many plots and some plots have various crops. Use of farmyard manure is in most cases confined to plots close to the homestead. Some young farmers can afford manure transportation to distant plots but aged farmers cannot. Rich farmers do not use inorganic fertilizers but rely instead on tight nutrient recycling. The use of some inorganic fertilizers by the intermediate and poor farmers is explained by the fact that they are relatively younger and ambitious. Consequently, they can venture into high value crops, mainly vegetables (Table 2) which require much attention in terms of management (labor – internal environment) and marketing (external environment). In general, there is very little use of inorganic fertilizers. This is attributed to the high prices of fertilizers and absence of two key external environment factors; suppliers and information (Figure 2) on how to use fertilizers. Limited use of fertilizers is characteristics for villages in Lushoto. In a survey involving 6 villages, only 5 % of farmers used inorganic fertilizers and 9 % used organic manure (Mowo et al., 2004)

Comparison of Local Soil Fertility Indicators with Soil Analytical Data and QUEFTS-Calculated Nutrient Uptake and Yield

Farmers in Maswa and Same districts (SWMRG project) using the most common local indicators of soil fertility made distinction between good and poor soils. These local indicators and their technical equivalents refer to fertility in a wider sense than just the supply of nutrients (Table 3). Soil related local indicators include soil color, presence of worms, cracks, salts, sand and gravel and drying up characteristics. Vegetation related indicators include dominance of certain types of plants, and crop performance.

Table 3. Most important local indicators of soil fertility according to participatory assessments in Same and Maswa districts, SWMRG Project

Local indicators		**Technical equivalent**
Good soil		
Black color		Rather high organic matter content
Cracks during dry season		High clay content
Good crop performance		Adequate supply of growth factors
Presence/ vigorous growth of certain plants*		Large supply of plant nutrients
Presence of plants in a dry environment		High water holding capacity (WHC)
Low frequency of watering		High infiltration rate and WHC
Abundance of earth worms		High biological activity, high organic matter content and neutral pH.
Poor soil		
Yellow and red colors		Low soil fertility / low organic matter content
Compacted soils		Presence of cementing materials (Al, Fe_2O_3 heavy clays) and low biological activity
Stunted growth		Physical, chemical and biological limitation
Presence of bracken ferns		Low pH
Salt visible on surface		High pH, high osmotic pressure
Presence of rocks and stones		Shallow soils

Source: Mrema, et al. 2003

[a] e.g. *Solunium indicum, Commelina spp,* a.o.

In Kwalei (AHI Project) farmers identified seven shrubs as being effective in improving soil fertility (Wickama and Mowo, 2001). Soils around these shrubs were sampled and analysed. Marks were assigned to the shrubs, with 10 for the shrubs of highest effectiveness and 2 for the shrubs of lowest effectiveness. In Table 4, the shrubs are arranged according to farmers' preference. The plant analytical data confirm the observations of the farmers. Highly ranked shrubs (scores 9 and 10) contained more N than the shrubs with score 2 (averages of 33.7 and 20.7 mg kg^{-1} N, respectively. *Vernonia spp. is* not a legume and the high N content might be a reflection of its efficiency in extracting soil N. Soils around the plants with high scores (> 8) were higher in exchangeable K than soils with low scoring shrubs (averages of 8.1 and 3.0 mmol kg^{-1} K, respectively) and than soils away from the plants.

Table 4. AHI Project. Farmers' preference (Score) for and nutrient mass fractions in shrubs, and properties of soils around the shrubs.

Shrub	**Score**	**Nutrients in Shrubs** (G kg^{-1})			**SOC**	**SON**	**P-Bray1**	**Exch. K**	**pH** (H_2O)
		N	P	K	g kg^{-1}		mg kg^{-1}	mmol kg^{-1}	
Vernonia subligera	10	36	0.25	4.7	22	4.5	8	9.4	6.5
Vernonia amyridiantha	9	34	0.23	4.5	21	4.5	10	10.8	5.0
Albizia schimperiana	9	31	0.32	1.3	16	4.3	13	8.4	5.1
Ficus vallis-choudae	8	30	0.23	4.4	57	6.6	9	3.6	6.4
Kalanchoe crinata	2	21	0.23	3.8	27	5.2	9	4.6	5.1
Bothriocline tementosa	2	21	0.27	1.5	20	4.3	7	1.6	4.9
Justicia glabra	2	20	0.27	2.1	27	5.7	10	2.8	6.3
Soils away from the shrubs					16	2.0	6	3.0	5.1

Source: Wickama and Mowo (2001)

Maize yields were calculated with the model QUEFTS. In Table 5, ranges of yields and nutrient uptake are presented. The lower values refer to a P-Olsen/P-Bray-1 ratio of 0.75, the higher values to a ratio of 2.5. Two groups may be distinguished: high yields (> 4 t ha-1) and low yields (< 3 t ha-1. Figure 3 is suggesting a rather good relationship between calculated yields and farmers' preference, but the graph may be misleading as it contains only two clusters of scores (9 - 10 and 2). The obvious exception is Ficus vallis-choudae that got a rather high score by farmers and had by far the lowest yield according to QUEFTS (Table 5). The soil was remarkably high in organic C (SOC), and hence probably had a high CEC. A combination of high CEC and low exchangeable K makes that the relative K saturation and by that available K is very low (Uribe and Cox, 1988). As QUEFTS takes this into account (Janssen et al., 1990), low yields were calculated for Ficus vallis-choudae soils. The relatively high score by farmers could be due to the important role of Ficus vallis-choudae in the preservation of water sources (Wickama et al., 2004).

Table 5. Calculated (QUEFTS) maize yield on soils around the shrubs, and calculated uptake of N, P and K (UN, UP, UK).

Soil around shrub	**Yield** ($t\ ha^{-1}$)	**UN** ($kg\ ha^{-1}$)	**UP** ($kg\ ha^{-1}$)	**UK** ($kg\ ha^{-1}$)	**N/P**[a]	**K/P**[a]	**YL**[a]
Vernonia subligera	5.0 – 7.1	181 – 225[b]	9.6 – 15.9	79 – 84	14.1 - 18.8	5.2 – 8.3	P
V. amyridiantha	4.1 – 7.3	119 – 143	7.4 – 15.8	127 – 161	9.1 – 16.0	10.2 – 17.1	P
Albizia schimperiana	4.4 – 6.9	124 – 147	8.2 – 18.8	130 – 159	7.8 - 15.1	8.5 – 15.8	P
Ficus vallis-choudae	1.5	54	7.7	14	7.0	1.8	K
Kalanchoe crinata	4.2 – 5.4	144 – 156	8.7 – 15.4	57 – 59	10.1 - 16.5	3.8 -6.5	P K
B. tementosa	2.4 – 2.9	97 – 100	5.2 – 9.9	28 – 29	10.1 – 18.8	2.9 – 5.4	K
Justicia glabra	2.5 – 2.6	91	10.1 - 13.0	23	7.0 – 9.0	1.8 - 2.3	K
Soil away from shrubs	2.5 – 3.7	64 – 69	5.5 - 10.2	55 - 59	6.8 -11.5	5.8 - 10.0	P

[a] Uptake ratios UN/UP and UK/UP, and yield limiting nutrient (YL)

[b] Ranges are based on assumed ratios of P-Olsen/P-Bray-1 between 0.75 and 2.5 For explanation see text.

Single soil parameters were not related to farmers' preference except exchangeable K. Also QUEFTS yields were related to exchangeable K (Figure 3). This is a clear indication that low yields are caused by K deficiency in the Lushoto area. Another indication that K is the most limiting nutrient in Lushoto follows from the uptake proportions of N:P:K. Optimum values for maize are 7:1:5.5 (Janssen and De Willigen, 2005). Table 5 shows that K/P was less than 5 for yields < 3 $t\ ha^{-1}$, even when P-Olsen was set at 2.5 times P-Bray-1. K uptake (UK) was then between 14 and 30 kg. For yields of more than 4 $t\ ha^{-1}$ UK was at least 57, but mostly more than 80 and even more than 125 $kg\ ha^{-1}$. Although on the soils away from shrubs K uptake was also around 57 kg, yields were not more than around 3 $t\ ha^{-1}$ because the uptake of N was just around 65 $kg\ ha^{-1}$. Where the calculated yield was more than 4 $t\ ha^{-1}$, the uptake of N was more than 120 $kg\ ha^{-1}$, and N/P was more than 7. So, at these yield levels, P was the yield limiting nutrient. The calculated uptake of P, however, did not differ very much among the fields. The uptake of P was enough for yields < 3 $t\ ha^{-1}$ as calculated for the K limited soils, but not enough for yields > 4 $t\ ha^{-1}$. This also explains why the effect of the translation of P-Bray-1 into P-Olsen on the calculated yield and P uptake was much smaller for the K-limited soils than for the other soils. Although these observations refer to calculated yields and uptake and not to really measured yields and uptake of maize grown on soils around the particular shrubs, they do support the hypothesis that farmers' disliked certain shrubs because they indicated low soil K supply.

For a long time K has been considered adequate in most tropical soils. However, in the humid areas with continuous cropping K deficiency is now common. Smithson et al. (1993) found a strong response by beans to K application in Lushoto while in Rwanda K deficiency is common in the highlands (Yamoah et al., 1990).

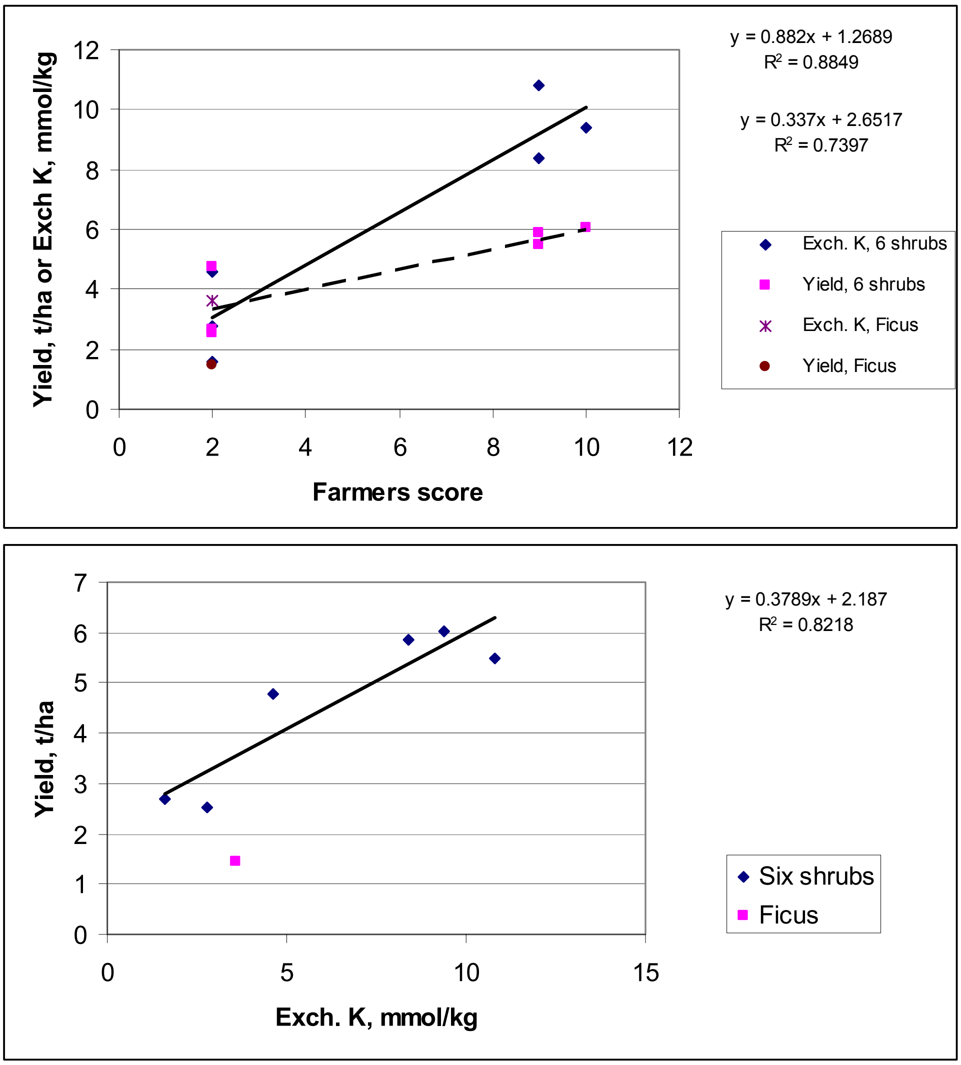

Figure 3. AHI Project. Exchangeable K and calculated maize yield (QUEFTS) in relation to farmers' preference of shrubs (top), and relation between exchangeable K and calculated maize yield (bottom). *Ficus vallis-choudae* is plotted separately because it behaved differently than the other six shrubs (see text). The significance value (P) is < 0.01 and 0.02 for R^2 of 0.88, 0.74 and 0.82, respectively.

Farmers in the AHI project ranked low inherent soil fertility (as evidenced by poor crop performance and prevalence of bracken ferns) and non-use of fertilizers as the most important soil fertility constraints. The analytical data of degraded soils along a slope in Table 6 are comparable to those of Smithson et al. (1993), but organic N and exchangeable K are lower. There was a trend of increasing pH down the slope. Similarly, organic matter, exchangeable K and available P increased somewhat down the slope probably due to erosion causing nutrients move down-slope from non-conserved fields. The same trend is seen in the yields calculated with the QUEFTS model (Table 7), but all yields are low and the differences are small. Yields were so strongly K-limited that no difference in yield was found between P-Olsen set at 0.75 and P-Olsen set at 2.5 times P-Bray-1. The calculated yields confirm the view of the farmers that inherent soil fertility is low.

Table 6. AHI Project. Some properties of degraded soils along a slope in Kwalei village, Lushoto benchmark site

Position on Slope	**Org. C** ($g\ kg^{-1}$)	**Org. N** ($g\ kg^{-1}$)	**P-Bray-1** ($mg\ kg^{-1}$)	**Exch. K** ($mmol\ kg^{-1}$)	**pH** (H_2O)
Lower (n = 5)	29 - 58		2 - 8	0.7- 1.8	6.0 – 6.8
Mid (n = 5)	31 - 49	1.6 – 2.5	1 - 4	0.3 -1.4	5.0 – 6.6
Upper (n = 2)	36, 41		1, 4	0.3, 1.1	5.1, 5.6

Source: Lyamchai and Mowo (1999)

Table 7. AHI Project. Calculated and uptake along a slope in Kwalei village, Lushoto benchmark site[a]

Position on slope	Yield kg ha^{-1}	UN kg ha^{-1}	UP kg ha^{-1}	UK kg ha^{-1}	N/P[b]	K/P[b]	YL[b]
Lower (n = 5)	598	25	3.4	7.0	7.4	2.1	K
Mid (n = 5)	489	21	2.8	6.1	7.5	2.1	K
Upper (n = 2)	486	21	2.8	6.0	7.5	2.1	K

[a] Yield and uptake (UN, UP, UK) were calculated with QUEFTS for data representing the middles of the ranges of soil data in Table 6 except for the upper slope where the averages of two values were used

[b] UN/UP and UK/UP, YL: Yield limiting nutrient

Comparison of Local Land Suitability Classification with Soil Analytical Data and QUEFTS-Calculated Nutrient Uptake and Yield

Using local indicators of soil fertility farmers in Maswa District identified two major land suitability classes based on cotton/maize (Class P) and rice cultivation (Class M) (Table 8). Variation within the major suitability classes indicated by P1 to P3 or M1 to M3 is based on decreasing suitability for the cultivation of the respective crop(s).

Table 8. Some properties of the soils of different land suitability classes in Maswa, SWMRG Project

Suitability Class	**EC** (mS/cm)	**Texture**	**Org. C** (g kg^{-1})	**Org. N** (g kg^{-1})	**P-Bray-1** (mg kg^{-1})	**Exch. K** (mmol kg^{-1})	**Exch. Na** (mmol kg^{-1})	**CEC** (mmol kg^{-1})	**pH** (H_2O)
P1 (n = 3)	0.08	Loamy sand	5	0.4	16	3.0	28	87	7.3
P2 (n = 2)	0.08	Sand clay loam	7	0.6	17	4.9	29	98	6.8
P3 (n = 3)	0.04	Loamy sand	5	0.5	14	3.5	18	102	6.6
M1 (n=3)	0.28	Sand clay loam	7	0.5	6	3.1	62	195	8.3
M2 n = 3)	0.08	Sand clay loam	5	0.4	6	1.7	44	134	7.6
M3 n = 2)	0.32	Sand clay loam	6	0.5	6	2.1	57	186	8.5

Source: SWMRG, 2003
P = Soils suitable for cotton and maize cultivation
n = Number of composite soil samples
M = Soils suitable for paddy rice cultivation

The farmers' classification was compared with analytical data for soil samples collected from the different suitability classes (Table 8). Generally, the soils from the different land suitability classes are all low in fertility although farmers consider classes P1 and M1 soil as fertile. Factors contributing to low fertility are the very low levels of organic nitrogen and organic carbon, and the high levels of exchangeable Na. Except for CEC which is increasing from sub-class 1 to 3, and for pH which is decreasing from sub-class 1 to 3 in land suitability class P, there is no consistent pattern in the other parametres measured. Soils in land suitability class M have higher pH and electrical conductivity (EC), and lower P-Bray-1 and exchangeable K than soils in suitability class P.

QUEFTS yields were calculated only for Classes P2 and P3 which had pH below 7.0. The QUEFTS-predicted yields of maize (Table 9) were higher for Class P2 than for Class P3, in agreement with the farmers' perception of soil fertility and with org. C, Org. N, P-Bray-1, Exch. K and pH (Table 8). From the N/P ratios it is inferred that the yields were N limited.

Table 9. SWMRG Project. Calculated (QUEFTS) maize yield and calculated uptake of N, P and K (UN, UP, UK).

Suitability class	Yield, t ha^{-1}	UN, kg ha^{-1}	UP, kg ha^{-1}	UK, kg ha^{-1}	N/P[a]	K/P[a]	YL[a]
P2[b]	2.2 - 2.3	39	7.2 – 12.2[c]	72	3.2 – 5.4	5.9 – 10.0	N
P3[b]	1.7 – 1.8	31	5.9 – 9.4	61	3.3 – 5.2	6.5 – 10.4	N

[a] N/P, K/P: uptake ratios UN/UP and UK/UP; YL: limiting nutrient

[b] Land suitability classes P2 and P3 in Maswa (see text). P is the soil suitable for cotton and maize cultivation.

[c] Ranges are based on assumed ranges of P-Olsen/P-Bray-1 between 0.75 and 2.5. For explanation see text.

FARM EXTERNAL ENVIRONMENT

Nutrient Management Strategies

In the AHI project, one of the on-farm trial managed by farmers tested the response of common beans (*Phaseolus vulgaris*) to *Vernonia subligera* or FYM applied with MPR as source of P. Unfortunately there was no FYM or *V. subligera* alone treatments. Sixty percent (60 %) of the farmers involved observed that the growth vigor of bean treated with either FYM or the green manure *V. subligera* combined with MPR was higher than for the MPR alone treatment (Figure 4). There was no significant difference in bean grain yield between FYM or *V. subligera* mixed with MPR but the two treatments differed significantly (P > 0.05) from the MPR alone treatment. The phosphorous content in the bean crop at flowering, following similar patterns as the bean grain yields, is high indicating that P was not the limiting factor. Probably the effect of FYM and *V. subligera* must be ascribed to K, in agreement with the QUEFTS-calculations in Section 4.1.2, and with the strong responses of beans to K found by Smithson et al. (1993) near the southern edge of the Usambara Mountains and by Anderson (1974) on Humic Ferralsols at altitudes between 1460 and 1830 m.

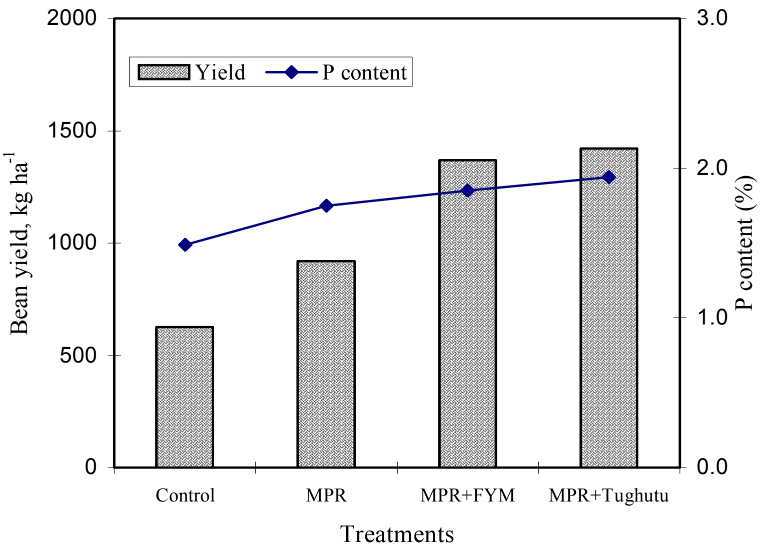

Figure 4. AHI Project. P content of bean crop at flowering and bean grain yield as affected by MPR and combinations of MPR with farmyard manure (FYM) or with *Vernonia subligera* (= Tughutu) in Kwalei. Coefficient of variation of yields is 24 % (P = 0.05). Source: Wickama et al., 2000.

Access to Information and Linking Farmers to Markets

One of the constraints identified by both projects was the limited exposure farmers had to available technologies and market opportunities. To address this 8 courses and tours were conducted involving 337 farmers (Table 1). 246 or 1.2 % of target farmers in the AHI Project and 91 or 0.5 % of target farmers in the

SWMERG Project participated). Although no systematic impact study has been done, some observations are worth noting as emanating from the study tours. For example, farmers in Kwalei (AHI Project) were slow in accepting soil conservation technologies because some of them are laborious. However, after a tour to the highlands of Kenya Meliyo et al. (2004) reported that there was an appreciable increase in the establishment of conservation structures. By the end of 2000 some 2,500 meters of bench terraces, 400 meters of hillside ditches and 100 meters of cut off drains had been constructed. Maize yield increased from 1.6 to 5.1 kg/plot due to soil conservation. Meanwhile, market tours are important in market developments (Figure 2) in that they enable farmers to access and negotiate with traders on favorable terms and hence improve their incomes.

Social Networks and Traditional Beliefs

In the AHI project the most important social network that influenced soil fertility management was formed by local institutions related to sharing of labour (Collective action). "*Ngemo*" is the word used by the local people, and it means pulling up of efforts to tackle issues jointly. Soil fertility management issues calling for collective action included manure transportation to distant plots and construction of soil conservation structures. Younger farmers were more active in this since they are still strong and ambitious.

Understanding some of the traditional beliefs some farmers indulge in (see below in italics) and how they relate to soil fertility management is important as this can provide a good entry point for addressing soil fertility constraints. For example, some farmers in Lushoto believe that giving away FYM will lead to poor performance of their crops or as is believed by some livestock keepers in Maswa (Rwehumbiza et al. 2003) will depress milk yields.

> *Magic power?*
> The teacher knew that the high paddy yield he was getting was due to improved management including fertilizer use. However, his neighbors were convinced that it was the work of a powerful 'magician' capable of relocating nutrients to the teachers' field. One of the neighbors requested the teacher to introduce him to the 'magician' for which he obliged on condition the neighbor follows whatever the teacher does. So when it was time for fertilizer application the neighbor was asked to take with him US $ 15 the fee for the 'magician'. They went to a fertilizer store and bought a 50-kg bag of Urea. The neighbors' paddy performed very well and he was convinced that it had nothing to do with magical transfer of nutrients.

Discussion

FARMERS CONSTRAINTS AND KNOWLEDGE

Several constraints related to the internal and external environment (Figures 1 and 2) make the smallholder farmers find themselves in a vicious cycle. They do not import the nutrients into the system equivalent to what they are removing with the harvested crops. This imblance leads to the downward trend in soil fertility commonly found in Sub-Saharan countries (Stoorvogel et al*.,* 1993). Further, due to limited nutrient use, yields are low and farmers cannot produce surplus for the market and hence cannot purchase fertilizers. Organic nutrient sources, which are about the only sources of nutrients available to smallholder farmers (Lyamchai et al., 1998), cannot cater for all the nutrients removed from the system, simply because the amounts are too small and also because of the nutrient losses associated with the poor management of these sources (Ramaru, et al. 2000).

The two projects discussed in this paper relied on participatory approaches with all actors in agricultural production, and there are indications that it worked (Stroud, 2003). Most important in this approach is to consider each others as equal partners in agricultural development (Ramaru, et al., 2000; Lyamchai et al., 2004). The major role of farmers is therefore to collaborate with the other stakeholders while the latter have to learn from farmers in order to contribute effectively in addressing problems confronting them (Kanmegne and Degrande, 2002). The approach of the two projects is conducive to share this knowledge because farmers are involved in all the stages of the research for development continuum. Farmers' knowledge has been used in identifying soil fertility constraints using local indicators of soil quality and in providing the necessary information in the generation of soil fertility and resource flow maps. This provides information on one of the internal environment factor, the soil (Figure 2), that will form the basis for further interventions. Essential was that the interaction with scientists has built confidence in the farmers because their knowledge in addressing soil fertility constraints was recognized.

SOIL FERTILITY EVALUATION AND NUTRIENT MANAGEMENT

The finding of this study that the results of the two evaluation systems - one based on indigenous farmers' knowledge, the other on model calculations – are in agreement is very encouraging. Although farmers' indigenous knowledge on soil fertility is important, we have encountered some striking examples that it does not always agree with formal scientific knowledge. Nevertheless, it is remarkable that the soil related local indicators in Tanzania (soil color, presence of worms, cracks, salts, sand and gravel and drying up characteristics) were practically the same as the ones used by farmers in Benin (Saïdou et al., 2004). It is, however, also remarkable that farmers did not mention *Tithonia diversifolia* as a preferred shrub, although it is known in the area. *Tithonia diversifolia* has been strongly supported as a green manure by ICRAF (Palm et al., 1997) and it would be appropriate to demonstrate its effectiveness to farmers in the AHI project area. *Vernonia subligera* has been promoted since the German colonial era in Tanzania for stabilization of conservation structures apart from its fertilizing value. It is also used as fodder for goats during dry seasons, as firewood and medicinally in the treatments of wounds (Wickama and Mowo, 2001).

Another discrepancy between farmer and science is the rather high score of *Ficus vallis-choudae* by farmers while it had by far the lowest yield according to QUEFTS (Table 4). Is the high SOC content of the surrounding soil a consequence of low decomposability of Ficus leaves which according to Palm et al. (2001) have a high lignin content? Further it may be questioned whether the shrubs identified as fertility promoters indeed have improved the soils or do grow on soils that already were good.
It is unfortunate that in the bean experiment (Section 4.2.1) no treatments with FYM and *V. subligera* alone were included, the more so because some farmers adopted combined application of organic sources and MPR. The organic sources (FYM and *V. subligera*) alone could have been as good as the combination of organic sources and MPR. The QUEFTS calculations suggest that K deficiency was a major soil fertility problem in the AHI project. Because of the emphasis on the use of MPR in the project, K deficiency may have been overlooked, although previous studies in the area (Anderson, 1974; Smithson et al., 1993) had shown that good responses to K could be obtained

So, various questions still have to be answered by scientists. Well-designed trials in the field are needed to find out whether farmers knowledge, laboratory analysis, interpretations of chemical soil tests by QUEFTS calculations or otherwise, or all have to be adjusted. Hence, not only evaluation by farmers but also yield predictions by QUEFTS need experimental verification. It was noted that farmers' perception of soil fertility is limited to what they see around them SWMRG (2003). This underscores the need of verification of farmers' observations through scientific assessment. Scientists should be able to show agreements and differences in evaluation criterions of farmers from different areas, and to identify the appropriate actions to be undertaken. In the present study, farmers' soil fertility evaluation could not simply be related to one particular soil property. It is here where the model QUEFTS shows to full advantage. It integrates the analytical data on SOC, SON, P, K and pH into one criterion: maize yield. In Table 10, the evaluation results have been grouped in five classes of decreasing soil fertility. The data of each class are averages of the values of three soils, presented in Tables 4 though 9. In the most right column the major causes of differences in soil fertility are indicated. As shown in Figure 3, it was obviously K that caused the difference between high and low valued shrubs. The shrub soils and Maswa soils diverge in soil organic matter, quantitatively (SOC and SON), as well as qualitatively (C/N). Values of P and K are lower, and those of pH (Table 10) and electrical conductivity (EC in Table 8) are higher in Maswa M, suited for rice, than in Maswa P, suitable for cotton and maize. Striking is that the soils with the highest organic matter content (Kwalei) were seen as very poor by the farmers as well as by QUEFTS.

Generally, soil organic matter is considered one of the most important and positive soil fertility characteristics. Black soil color is related to organic matter, and it is mentioned as positive in most farmers' soil fertility evaluations (Table 3; Saïdou et al, 2004). The poor quality of Kwalei soils finds expression in low P and K, and in high C/N. Farmers have obtained very low yields on these degraded soils (Lyamchai and Mowo, 1999). In Table 10, the soil parameters most clearly related to farmers evaluation and QUEFTS yields are C/N and exchangeable K. These parameters also proved important in the study by Tittonell (2003) who observed that difference in soil fertility were explained by C, N, P, K and CEC.

Table 10. Soil analytical data[a] and calculated QUEFTS yields (middle of range) of five groups of soils ranked in order of farmers soil fertility evaluation.

Name	Yield	SOC	SON	C/N	P-Bray-1	Exch. K	pH	Major difference with lower class
	($t\ ha^{-1}$)	($g\ kg^{-1}$)	($g\ kg^{-1}$)		($mg\ kg^{-1}$)	($mmol\ kg^{-1}$)	(H_2O)	
Shrubs, high score	5.8	20	4.4	4.4	10.3	9.5	5.5	K
Shrubs, low score	3.3	25	5.1	4.9	8.7	3.0	5.4	SOC, SON, C/N
Maswa P	2.0[a]	6	0.5	11.4	15.7	3.8	6.9	P, K, pH
Maswa M	n.c [b]	6	0.5	12.8	6.0	2.3	8.1	C/N, P, K
Kwalei	0.5	41	2.1	19.4	3.3	0.9	5.8	

[a] Soil data and yields refer to the middle range of values found for the particular group

[b]Average of Class P2 and P3

[c] Yields were not calculated because pH(H_2O) was more than 7 (see text)

EXTERNAL AND INTERNAL DECISION ENVIRONMENTS

Heterogeneity among farmers leads to different decisions by households. Most of these differences constitute the internal environment influencing a farmer's decision making (Figures 1 and 2). Ley et al. (2002) observed that wealthy farmers are more likely to afford expensive fertilizers, or might own livestock and hence have more organic manure (Ouédraogo, 2004). Meanwhile, older couples might find it difficult to transport manure to distant plots compared to young farmers. It is the role of researchers and extension workers to recognize and work with these differences for better targeting of technologies. The two projects have taken this into consideration whereby interactions with farmers always consider their different categories.
Finally, links with markets and training on enterprise selection will enable poor farmers to make some cash income. Although the effects of such linkages are yet to be studied, we believe that if farmers can have some cash income to meet domestic needs they could be convinced to invest more into soil fertility to derive even more cash. Given that most smallholder farmers are poor, a cascade of steps to gradually enable them to get into the market economy is proposed. In this approach farmers should be provided with the necessary knowledge to manage and use organic resources more efficiently. Through awareness creation on the need to replenish nutrients taken out of the farming system they could be convinced to start purchasing some inorganic fertilizers to supplement their organic sources.

The project tours and courses have exposed the farmers to better land husbandry practices by their fellow farmers elsewhere. The impact of such exposures has been encouraging. For example, Tenge (2005) working in Lushoto observed that adoption of technologies by farmers was related, besides to their level of education, to the extent of contact they have had with development projects.

Conclusions

Participatory approaches as used by the AHI and SWMRG projects have shown that there is an opportunity to reverse the declining trends in soil fertility in smallholder farms in northern Tanzania. This is because the approaches allow for participation of all stakeholders and notably farmers whose indigenous knowledge and experience are useful in soil fertility evaluation and management. However, because farmers' evaluation of soil fertility is relative to what they see around them there is a need to verify their observations. On the other hand, also the interpretation of laboratory analysis by models like QUEFTS requires continuous and critical validation. From model calculations it was established that in Lushoto K was the most limiting nutrient for maize yields lower than 3 $t\ ha^{-1}$ and P for yields higher than 4 $t\ ha^{-1}$. Meanwhile the soil parameters most related to farmers evaluation and QUEFTS yields are C/N and exchangeable K. The capacity of local communities in soil fertility evaluation and management should be enhanced by enabling them access the available information and knowledge through short training sessions and tours. Well-designed trials in the field are needed to find out whether farmers knowledge, laboratory analysis, interpretations of chemical soil tests by QUEFTS calculations or otherwise, or all have to be adjusted.

References

Anderson, G.D., 1974. Bean responses to fertilizers on Mt Kilimanjaro in relation to soil and climatic conditions. East African Agric. Forestry J. 39, 272-288.

Barrios, E., Bekunda, M., Delve, R., Esilaba, A. and Mowo, J., 2002. Identifying local soil quality indicators. Methodologies for decision making in natural resource management. Eastern African Version. International Center for Tropical Agriculture, Cali, Colombia.

Bebbington, A., 1998. "Capitals and Capabilities". http://www.fao.org/DOCREP/006/

Bebbington, A., 1999. Capitals and capabilities: a framework for analyzing peasant viability, rural livelihoods and poverty. World Development 27, 2021-2044.

Campbell, B., Sayer, J.A., Frost, P. Vermeulen, S., Ruiz Pérez, M., Cunningham, A. and Prabhu, R., 2001. Assessing the performance of natural resource systems. Conservation Ecology **5**(2): 22. [online] URL: http://www.consecol.org/vol5/iss2/art22/

David, F.R., 2001. Strategic Management Concept. Prentice Hall. Upper Saddle River.

Defoer, T., 2002. Learning about methodology development for integrated soil fertility management. Agricultural Systems 73, 57 – 81.

Defoer, T. and Budelman, A. (Eds.), 2000. Managing Soil Fertility in the Tropics. A Resource Guide for Participatory Learning and Action Research. KIT Publishers, The Netherlands.

de Jager, A., Onduru, D. and Walaga, C., 2004. Facilitated learning in soil fertility management: assessing potentials of low external input technologies in east African farming systems. Agricultural Systems 79, 205 – 223.

German, L.A., Mowo, J.G. and Kingamkono, M., (in press). A Methodology for Tracking the 'Fate' of Technological Interventions in Agriculture. Agriculture and Human Values.

Gomez-Limon, J.A., Riesgo, L. and Arriaza, M., 2000. Agricultural Risk Aversion Revisited: A Multi-criteria Decision Making Approach., Contributed paper to the Xth EAAE Conference, Zaragoza, August 2000.

Hellin, J., 2003. From soil erosion to soil quality. LEISA Magazine on Low External Input and Sustainable Agriculture. December 2003. Vol. 19, No. 4.

Izac, A. M. N. and Sanchez, P. A., 2001. Towards a natural resource management paradigm for international agriculture: the example of agroforestry research. Agricultural Systems 69, 5 - 25.

Janssen, B.H. and De Willigen, P., 2005. Ideal and saturated soil fertility as bench marks in a framework for soil fertility rating and nutrient management. Agriculture, Ecosystems and Environment. Vol. 116, No. 4.

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.

Johansson, L., 2001. Ten million trees later. Land use change in the West Usambara Mountains. The Soil Erosion and Agroforestry Project (SECAP) in Lushoto District. 1981 – 2000. 163 p.

Kanmegne, J. and Degrande, A., 2002. From alley cropping to rotation fallow: Farmers' involvement in the development of fallow management techniques in the humid forest zone of Cameroon. Agroforestry Systems. 54: 115 – 120.

Keeney, D. R., 1997. Sustainable agriculture and the environment. Proceedings 1997 International Symposium on Sustainable Agricultural Development Compatible with Environmental Conservation in Asia. JIRCAS, Tskuba, Japan.

Ley, G., Baltissen, G., Veldkamp, W., Nyaki, A. and Schrader, T., 2002. Towards integrated soil fertility management in Tanzania. Developing farmers' options and responsive policies in the context of prevailing agro-ecological, socio-economic and institutional conditions. KIT Publishers, Amsterdam.

Lightfoot, C. Dalsgaard, J.P., Bombao, A.M. and Fermin, F., 1992. Farmer participatory approaches for managing and monitoring sustainable farming systems. International Centre for Living Aquatic Resources Management (ILCRAM). Manila, Philippines.

Lyamchai, C. J., Lyimo, S. D., Ndondi, R.V., Owenya, M. Z., Ndakidemi, P. A. and Massawe, N. F., 1998. Participatory Rural Appraisal for Kwalei Catchment, Lushoto District. The African Highlands Ecoregional Programme (AHI), Selian A.R.I Arusha, Tanzania.

Lyamchai, C.J. and Mowo, J.G., 1999. African Highlands Initiative (AHI) Progress Report for Lushoto AHI Benchmark Site, Tanzania. Ministry of Agriculture and Food Security, Selian Agricultural Research Institute, Arusha, Tanzania. 1999.

Lyamchai, C.J. and Mowo, J.G., 2000. African Highlands Initiative (AHI) Progress Report for Lushoto AHI Benchmark Site, Tanzania. Ministry of Agriculture and Food Security, Selian Agricultural Research Institute, Arusha, Tanzania. 2000.

Lyamchai, C.J., Mowo, J.G. and Wickama, J.M., 2004. Managing new working relationships: Partnership and networking. Paper presented at the AHI Regional Conference, 12 – 15 October 2004, Nairobi, Kenya.

Meliyo, J.L., Mansoor, H.A., Masuki, K.F.G., Mowo, J.G. and Shemdoe, R.S., 2004. Social and Biophysical Profile of the Baga watershed, Lushoto, District, Tanzania. AHI Lushoto Benchmark site. Report No.1, 2004.

Menon, R.G., Chien, S.H. and Hammond, L.L., 1990. Development and evaluation of the Pi soil test for plant-available phosphorus. Commun. Soil Sci. Plant Anal. 21, 1131-1150.

Mowo, J.G., 2000. Effectiveness of phosphate rock on Ferralsols in Tanzania and the influence of within-field variability. Ph.D. Thesis. Wageningen University, The Netherlands.

Mowo, J.G., German, L., Getachew, A.F., Mbakaya D.S., Endrias, G. and Tesema, T., 2004. Local institutions and their role in natural resource management in the East African highlands. Paper presented at the Regional AHI Conference on Integrated Natural Resource Management in Practice: Enabling Communities to improve Mountain Livelihoods. 12 – 15 October 2004; Nairobi, Kenya.

Mowo, J.G., Shemdoe, R.S. and Stroud, A., 2005. Interdisciplinary Research and Management in the highlands of Eastern Africa: AHI experiences in the Usambara Mountains, Tanzania. Contribution to the book: Interdisciplinary Research and Management in Mountain Areas. Ed. M. Price. In press.

Mrema, J.P., Mowo, J.G., Shetto, M.C. Kajiru, G.J., Ngatoluwa, R. and Rwehumbiza, F.B., 2003. Local strategies of soil fertility management and their impacts on soil fertility and productivity. Report prepared for the NRSP Project R8115, SWMRG (Soil Water Management Research Group), Sokoine University of Agriculture, Morogoro Tanzania. Report R7.

NRI., 2000. Institutional support for integrated nutrient management. Natural Resource Institute (NRI), UK.

NSS., 1990. Laboratory procedures for routine soil analysis. 3rd edition. Ministry of Agriculture and Livestock Development, National Soil Service (NSS), ARI Mlingano, Tanga, Tanzania.

Okalebo, J. R., Gathua, K. W., and Woomer, P. L., 1993. Laboratory methods for soil and plant analysis: A working manual - KARI - Rost. 88 pp.

Ondersteijn, C.J.M., Giesen, G.W.J. and Huirne, R.B.P., 2003. Identification of farmers' characteristics and farm strategies explaining changes in environmental and economic performance of dairy farms. Agricultural Systems 78, 31-55.

Ouédraogo, E., 2004. Soil quality improvement for crop production in semi arid West Africa. Ph.D. Thesis. Wageningen University. The Netherlands.

Palm, C.A., Gachengo, C.N., Delve, R.J., Cadisch, G, Giller, K.E., 2001. Organic inputs for soil fertility management in tropical agroecosystems: application of an organic resource database. Agriculture, Ecosystems and Environment 83, 27-42.

Palm, C.A., Myers, R.J.K. and Nandwa, S.M., 1997. Combined use of organic and inorganic nutrient sources for soil fertility maintenance and replenishment. In: Buresh, R.J., P.A. Sanchez, and Calhoun, F. (Eds.), Soil fertility in Africa is at stake. SSSA Special Publication Number 51. Soil Science Society of America, American Society of Agronomy, Madison, USA, 193-217.

Ramaru, J., Mamabolo, Z. and Lekgoro, J., 2000. Improving soil fertility management in South Africa: learning through participatory extension approaches. Managing Africa's Soils No. 19.

Rwehumbiza, F.B., Mowo, J.G. and Ngatoluwa, R.N., 2003. Soil fertility management options. Report prepared for the NRSP Project R8115, SWMRG (Soil Water Management Research Group), Sokoine University of Agriculture, Morogoro Tanzania. Report R13.

Saïdou, A., Kuiper, T.W., Kossou, D.K., Tossou, R., Richards, P., 2004. Sustainable soil fertility management in Benin: learning from farmers. NJAS-Wageningen J. Life Sciences 52, 349-369.

Sanchez, P.A., 2002 Soil fertility and hunger in Africa. Science, Vol. 295, No. 5562. 2019 -2020.

Smaling, E.M.A. and Janssen, B.H., 1993. Calibrating of QUEFTS, a model predicting nutrient uptake and yields from chemical soil fertilty indices. Geoderma 59, 21-44.

Smithson, J.B., Edje, O.T. and Giller, K.E., 1993. Diagnosis and correction of soil nutrient problems of common bean *(Phaseolus vulgaris)* in the Usambara Mountains of Tanzania. J. Agric. Sci., Cambridge 120, 233-240.

Stoorvogel, J.J., Smaling, E.M.A. and Janssen, B.H., 1993. Calculating soil nutrient balances in Africa at different scales. Supra-national scale. Fertilizer Research, 227 – 235.
Stroud, A., 2003. Linked Technologies for Increasing Adoption and Impact. African Highlands Initiative (AHI), brief No. 3. Enabling Communities to Regenerate Mountain Landscapes.
SWMRG, 2002. Improvement of soil fertility management practices in rainwater harvesting systems. A collaborative project between the Soil Water Management Research Group (SWMRG) of Sokoine University of Agriculture, Tanzania and the University of Nottingham, UK.
SWMRG, 2003. Soil Sampling and Analysis for Soil Fertility Evaluation (Nutrient Database) of the Soils from WPLL and Maswa Districts. ANNEX B10a. Soil Water Management Research Group (SWMRG), Sokoine University of Agriculture, Morogoro, Tanzania.
Tenge, A. J. M., 2005. Participatory appraisal for farm level soil and water conservation planning in West Usambara highlands, Tanzania. PhD Thesis Wageningen University, Netherlands
Tittonel, P., 2003. Soil fertility gradients in smallholder farms of western Kenya. M.Sc. Thesis. Production Ecology, Wageningen University. The Netherlands.
Uribe, E., and Cox, F.R., 1988. Soil properties affecting the availability of potassium in highly weathered soils. Soil Science Soc. Am. J. 52, 148-152.
Van der Ploeg, J.D. ,1993. Styles and classification of farming. Nature of agriculture development processes. Journal of Social Sciences for Agriculture 8, 50-70.
Whiteside, M., 1996. Encouraging sustainable smallholder agriculture in Southern Africa in the context of agricultural services reform. Natural Resources Perspectives, Overseas Development Institute Number 36, July 1998.
Wickama, J. M., Mathias, S. and Kiluvia, V., 2004. Community Perception on Resource Degradation: The Case of Trees and Water Sources in the Baga Watershed, Lushoto District. Lushoto AHI Site Report No 4: 2004. Directorate of Research and Development (DRD) Ministry of Agriculture and Food Security Tanzania.
Wickama, J. M., Mowo, J. G., 2001. Indigenous nutrient resources in Tanzania. Managing African Soils No. 22. February 2001.
Wickama, J. M., Veldkamp, W.J., Ley, G.J., Nyaki, A.S., 2000. Integrated soil fertility and plant nutrient management research in Tanzania: The National Soil Service Experience. Paper INCO-CA Workshop on Diversity, Policy and Scaling-up. Entebbe, Uganda.
Yamoah, C.F., Burleigh, J.R., and Malcolm, M.R., 1990. Application of expert systems to study of acid soils in Rwanda. Agriculture, Ecosystems and Environment, 30, 203 – 218.

The AHI Working Papers Series

The AHI Working Papers Series was developed as a medium for AHI staff and partners to synthesize key research findings and lessons from innovations conducted in its benchmark site locations and institutional change work in the region. Contributions to the series include survey reports; case studies from sites; synthetic reviews of key topics and experiences; and drafts of academic papers written for international conferences and/or eventual publication in peer reviewed journals. In some cases, Working Papers have been re-produced from already published material in an effort to consolidate the work done by AHI and its partners over the years. The targets of these papers include research organizations at national and international level; development and extension organizations and practitioners with an interest in conceptual synthesis of "good practice"; and policy-makers interested in more widespread application of lessons and successes.

Acknowledgements

The African Highlands Initiative (AHI) expresses its gratitude to the Department for Research and Development of Tanzania (DRD); Ethiopian Institute of Agricultural Research (EIAR); FOFIFA of Madagascar; Kenyan Agricultural Research Institute (KARI); National Agricultural Research Organization of Uganda (NARO); International Centre for Tropical Agriculture (CIAT); World Agroforestry Centre (ICRAF); Tropical Soils Biology and Fertility Institute of CIAT (TSBF-CIAT); International Maize and Wheat Centre (CIMMYT); International Potato Centre (CIP); International Institute of Tropical Agriculture (IITA); Ministries of Agriculture and NGO partners operating in AHI Benchmark Sites of Ethiopia, Kenya, Tanzania and Uganda for the technical, facilitation and partnership roles they have played in our effort to develop tools and methods in Integrated Natural Resource Management together with local communities.

AHI is very thankful to the donors which tirelessly financed the regional and global engagement of AHI in improving our development and natural resource management research endeavours, namely the Swiss Development Cooperation (SDC); International Development Research Council (IDRC); Ministerie van Buitenlandse Zaken (the Netherlands government); Cooperazione Italiana (Italian government); the Rockefeller Foundation; the European Commission; the Consultative Group on International Agricultural Research (CGIAR); the Department for International Development (DfID); the Collective Action and Property Rights Programme of the CGIAR (CAPRi); the International Potato Center (CIP) and ECAPAPA.