Farmers' indicators for soil erosion mapping and crop yield estimation in central highlands of Kenya

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Tropical Resource Management Papers,
ISSN 0926-9495

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Documents sur la Gestion des Ressources Tropicales, ISSN 0926-9495

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Tropical Resource Management Papers, No. 62 (2005); ISBN 90-6754-881-2

Also published as thesis (2005), Wageningen University ISBN 90-8504-157-0

Farmers' indicators for soil erosion mapping and crop yield estimation in central highlands of Kenya

EROAHI Report 1

The work reported in this book has been carried out as part of the project 'Development of an improved method for soil and water conservation planning at catchment scale in the East African Highlands' (EROAHI). This project was funded through the Dutch/Swiss 'Fund for Methodological Support to Ecoregional Programmes', and the Dutch 'Partners for Water Programme'.

EROAHI was carried out by the following institutions:

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To

The memory of my father

Financial Support for the printing of this thesis was obtained from the Dr. Judith Zwartz Foundation, Wageningen, The Netherlands.

Acknowledgements

The research idea that led to the writing of this thesis started with a surprise visit of two Dutch scientists to KARI-Embu in 1998. The research idea made great impression to both my Centre Director and to myself. Since then the idea was funded and the research was not only very innovative but led to writing of a memorandum of understanding among several institutions, namely ALTERRA (Netherlands), Erosion and Soil & Water Conservation Group of the Wageningen University (Netherlands), Kenya Agricultural Research Institute (KARI) – Embu and the Agricultural Research Institute of Tanzania - Mlingano. It was through this that the opportunity to pursue PhD studies was made possible. I would wish to acknowledge the efforts put in by my project leaders to ensure that the budget was adjusted to accommodate sandwich PhD studies, namely Mr. SP Gachanja (KARI-Embu Centre Director), Ir. Rik vanden Bosch and Dr. Geert Sterk. This led to my first visit to the Wageningen University in 2000 (November) to start the first six months to write my PhD proposal and do some coursework under the supervision of Dr. Geert Sterk. It was then that I met my promoter Prof. Leo Stroosnijder. The initial talk and logistic support I received from Prof. Stroosnijder and Dr. Sterk made me develop a winning attitude towards the task of undertaking the PhD programme. This was confirmed through the enabling environment experienced in my overall three-time visits to the Wageningen University. A team spirit in the Erosion and Soil & Water Conservation Group was explicit through the group parties, excursions, coffee/tea breaks, birthday parties and several dinner invitations by individual staffs. Prof. Leo, Dr. Sterk, Dr. Jan, Ir. Dirk, Ms Olga, Ir. Anton, Ms Helena, Ms. Jackoline, Mr. Ferko, Dr. Saskia, Ms. Jolanda and the rest of the group you are worthy mentioning because you made my stay in Wageningen very homely and may God bless you greatly.

It was through the trust put in me and encouragement received from my friendly supervisor Dr. Geert Sterk that this thesis came to be in its present form. Your two time visit to Kenya, ensuring that Prof. Leo comes along, boosted my initiative greatly. It was through your guidance, critical evaluation and organizational skill that made marrying of the farmers' and scientific knowledge basis possible hence introducing a different perspective in soil erosion assessment. I would also wish to thank the Master of Science students who carried out their thesis studies in Kenya, Embu. Specifically work of John Ireri (Egerton University-Kenya), Ir. Sander Groenenberg and Ir. Sjoerd (WUR) greatly contributed to some aspects of this thesis. I also acknowledge Mr. Mugo Rimui and Leonard Musiega for their effort in field data collection, laboratory analysis and data entry.

The research idea would not have achieved the much it did had the farmers of Gikuuri catchment not been available to educate me on what they know and how they perceived the on-going land degradation. I will always use my experience of working with you to adapt to another community. Though I briefly stayed with the farmers of Kwalei catchment in Lushoto District of West Usambara highlands (Tanzania), I enjoyed their freedom to share with me their knowledge of soil erosion indicators. For that matter I thank them and the project leader Mr. Albino Tenge for the logistic support and traditionally friendly Tanzanian culture.

Finally I wish to express a million dollar thanks to my family who had to bear with me during the tough three years of research and long hours of staying in the office and sometimes extending it at home. Were it not for my wife (Beatrice) to convince my sons (Bildad and Ben-Solo) and daughter (Bilha) that the situation was but for a short time my children almost misinterpreted my

love for them. Anyhow they all proved to be patient and endured even with my last stay in the Netherlands, especially for my son Bildad, who during the same period needed my fatherly support while doing his high school entrance examination.

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Chapter 1

INTRODUCTION

Introduction

The highlands of Kenya cover only 18% of the country but hosts 70% of the nation's population. The highlands, which are located along the equator and in the central part of the country, have reliable rainfall, above 1200 mm per year and fertile volcanic soils. They therefore create a high potential for intensive dairy livestock keeping, ranching and rainfed agriculture (Jaetzold and Schmidt, 1983; GoK, 1992; GoK/UNEP, 1997). Common crops include tea, coffee, sugarcane, maize, beans and wheat, besides a range of horticultural crops and irrigated cereals. The region is under high land pressure due to increasing population (GoK/UNEP, 2001). Most of the agricultural land has so far been subdivided to the smallest land holdings that are no longer economically viable for smallholders' subsistence. Eighty-three percent of the farmers in this region are smallholders whose average percapita landholding is between 0.01 and 2.9 ha (Thomas, 1988). For the past three decades the forest reserves and other fragile and ecologically unsuitable environments have faced threat from the increasing population in search of fuelwood, timber and food for subsistence. Consequent impact of these exploitations could be blamed for the current environmental degradation hazards like mass movements, drying of water springs and rivers, floods and increased rates of sedimentation in dams and lakes (Westerberg and Christiansson, 1999; KLA 2000). Practices like cultivation on the restricted slope gradients (>55%) without soil and water conservation (SWC) measures and tillage along riverbanks have accelerated the degradation, raising nationwide concern of the increasingly degraded environment (Thomas, 1988; KLA, 2000).

Given the importance Kenya places on its land-based resources (primary basis for its economy) and whose productivity was fast declining, soil conservation legislations were put in place to protect the fragile ecosystems and combat land degradation (Thomas et al., 1997). Areas that attracted particular concerns were the humid highlands, given their important contribution to agro-industrial development in the country (Thomas, 1988; Ståhl, 1993; Pretty *et al*., 1995; Westerberg and Christiansson, 1999). The legislations were imposed to ensure land and water resources were utilised in a sustainable manner to support the fast growing population in view of the fact that there was no alternative land available to expand to and cope with increasing food deficit. Some of the enforced regulatory measures included the mandatory construction of bench and/or *fanya juu* terraces prior to establishment of coffee trees; residue mulching was required for the newly established tea seedlings and in food crop farms installation of *fanya juu* terraces and grass strips were recommended. Cultivation was however restricted to slopes not beyond 55% and conservation was mandatory on farms inclined on slopes exceeding 12% (Thomas *et al*., 1997).

Though initially the laws governing the construction of erosion controlling measures were by coercion, during the colonial period, the new independent Government motivated farmers to conserve their land by providing monetary incentives, especially for the construction of cut-off-drains and artificial water ways. Other non-monetary incentives included the provision of fodder grasses and seedlings of fruits and trees to farmers in catchment areas (Wenner, 1988; Thomas, 1988). Despite these benefits, farmers did not extend the conservation measures when incentives were withdrawn. Though farmers were meant to realize the importance of these technologies, the adoption was not embraced. A reaction that could be attributed to the approach adopted to enforce the SWC regulations, strongly showing the top-down attitude similar to the approaches used during the colonial era (Thomas, 1988). Other reasons for the low adoption rate were lack of consultation between the farmers and the experts on the most appropriate and cost-effective measures to implement. But also the haphazard manner in which SWC plans were executed in the target area undermined the benefits of the installed SWC measures (Thomas *et al*., 1997).

As a result, a Catchment Approach (CA) concept was conceived, which mobilised and motivated all farmers in a specific focal area to conserve their cultivated land on their own terms (Pretty, *et al*., 1995). Under the CA the experts from the agriculture extension services assisted farmers in developing land management plans that ensured soil and water resources were utilized in a sustainable manner. The experts also trained the catchment committee members on how to layout the SWC plans and to maintain tree nurseries and grass bulking plots following the catchment bylaws. Other activities during the period of the CA included organizing educational tours, farmer-field days, and provision of leaflets. Despite the much resources put in propagating the SWC activities the actual adoption of the planned SWC measures was not spontaneous among smallholder farmers. The haste to shift to the next catchment area and the fact that SWC campaigns were being emphasised in areas where soils were already degraded, made it quite difficult for poor resourced farmers to embrace the ideas in the short period (one year) the CA focussed its campaigns in a focal area. Emphasising the need to involve farmers in SWC programmes, Rickson *et al*. (1993) observed that sustainable land management was an enduring process that required constant farmers' involvement and ensuring that they clearly comprehended the linkages between the glaring soil erosion problems and their livelihood without which expert-formulated recommendations were bound to fail. Moreover, an evaluation on activities of the CA revealed some gaps or weaknesses inherent in the implementation of the concept and which made it not realise overwhelming acceptance (Admassie, 1992). These gaps have persisted in spite of several modifications the CA concept has undergone over the years (e.g. Pretty *et al*., 1995; Kiara *et al*., 1999; Baya, 2000).

The first gap identified the apparent lack of satisfactory involvement of the farming community in identification and quantification of the erosion problems in the catchment area. Instead the extension officers led the community in understanding the perceived problems using their own experiences and criteria. The farmers' knowledge that is based on the experiences of distinguishing between good and poor soils was not consulted. It is an established fact that farmers know when soil erosion has taken place and can identify its effect by observing changes on the soil surface characteristics and performance of their crops (Josh and Sinclair, 1998; Steiner, 1998). It has also been established that for SWC programmes to succeed, integration of farmers' knowledge is of paramount importance (Hudson, 1992; Rickson *et al*., 1993). Primarily because the knowledge from the farmers can contribute to the design of ecologically appropriate and adaptable conservation techniques thus providing SWC options, which different farmers in a variety of circumstances can accept and adapt to their circumstances. Others have observed that experts can gain more insight of the actual problems that would improve packaging of technologies by allowing farmers to participate in diagramming their local circumstances (Lighfoot, 1989; Conway, 1989). Therefore active participation of the farmers in a development programme can lead to spontaneous uptake of technologies that specifically address the problems they can clearly envision as a community.

The other gap identified related to the CA emphasis on planning SWC measures at individual farms instead of at a catchment scale. Realising that the CA concept was intended to counter the haphazard implementation of SWC measures, formerly practiced, planning at farm scale was not going to achieve the envisaged uniform implementation of the planned SWC measures. However, SWC is most effective when the entire community is involved to carry out SWC planning at a catchment scale. It provides them with better reflection of their problems and motivation to solve them communally. Turton and Farrington (1998) observed that an approach that reflects on resource decline at catchment scale rather than at farm-level had potential to catalyse widespread and equitable use of land-based resources among the communities. Therefore, an important function of planning at a catchment scale is that it helps to identify farms that would require more investment and pinpoints areas that require communal actions. It is only after such an overview that planning at farm scale may make sense or becomes justifiable. By focussing on individual farm planning the public properties were not considered e.g. roads and schools, shopping centres and factories, and yet often sources of pollution and destructive overland flows onto private lands and drainage systems.

The aim of this study was to develop a tool for participatory soil erosion mapping at field and catchment scales. This tool is based on the farmers' knowledge and perceptions of soil degradation and uses farmers' indicators for soil erosion and sedimentation.

The study outline

This study was carried out in an area representative of the highlands in central Kenya. The study site was Gikuuri catchment (00^{o} 26´S, 37^{o} 33´E at an elevation range of 1302-1500 m) in Embu District (Fig. 1). It has an area of about 5 km^2 and hosts a population of about 657 smallscale households. They practice intensive mixed cropping systems consisting of food crops such as maize (*Zea mays*), potato (*Solanum tuberosum*), banana (*Musa,* Species) and beans (*Phaseolus vulgaris*). Cash crops are mainly the coffee (*Coffea arabica*, var.), macadamia (*Macadamia integrifolia* var.) and khat (Kat) or *mirraa* (*Catha edulis*). Dairy cattle are kept but strictly on zero-grazing system due to small land sizes. The study area falls within the humid and sub-humid agroecological conditions (Jaetzold and Schmidt, 1983). The soils are developed from volcanic rocks and they are very deep (>1.6 m) and of high potential fertility. The rainfall regime is bi-modal and distributed over the long rainfall (LR) and the short rainfall (SR) seasons with peaks in April and November, respectively. The mean annual rainfall is about 1289 mm and daily temperatures are between a mean of 15^{o}C (minimum) and 27^{o}C (maximum). Despite the abundant rainfall for crop growth, the mean monthly potential evapotranspiration demand is higher than the monthly rainfall in the year except during the distinct rainfall seasons (Fig. 2). Rainfall is often of high intensity resulting in severe soil erosion events at the onset of the rainy season a time when the soils are bare. Therefore steep slopes tend to be relatively susceptible to water erosion as signified by widespread exposure of subsoil, rills and gullies on the hillslopes in the study area. Past efforts to mobilise farmers to embrace soil and water conservation measures through the CA did not improve the situation, as many fields are not conserved today.

Therefore this study was sited in this catchment to assess the level of farmers' knowledge and perceptions on soil erosion processes and SWC measures. Issues pertaining to constraints to adoption of the recommended SWC measures and how farmers' knowledge is applied to judge between good and poor land managers using a set of land management criteria are discussed (Chapter 2). Given the widespread erosion problems in the area, it was of interest to establish what indicators the farmers associated with different degrees of soil erosion and how they used them to estimate the extent of soil erosion damage. It was also important to get the farmers to identify these erosion indicators in their vernacular language and describe how they distinguished them among each other. Though farmers may not be aware of the amount of soil loss from their farms, they associate specific soil erosion indicators to different rates of soil loss. However the knowledge of the extent of soil erosion damage can also be useful in delineating farms into segments that indicate different erosion status and requiring different soil management attentions (Chapter 3). The study further attached quantitative values of soil loss and crop yields to the farmers' soil erosion indicators, widely exhibited on the cultivated fields (Chapter 4). Though extent of erosion was mapped following field-by-field assessment of soil erosion indicators, farmers produced a catchment scale soil erosion status map, based on spatial spread of different erosion indicators. In order to put the farmers' knowledge of spatial soil erosion status and predictions of crop yields in eroded fields into widescale perspective, their assessment was compared with a scientific approach. The disparities, strengths and weaknesses are discussed (Chapter 5). However, the major output of this study was to finally develop a tool that could improve farmers' decisions in land management through SWC activities. The tool addresses how farmers can be involved to envision the soil erosion status in their local environment and the impact of soil erosion on crop yields. In a separate study (Tenge *et al.*, 2005) a second tool was developed and applied in this study site. This tool introduces improvements in farmers' capability to make informed decisions by illustrating how to identify a suitable SWC options through the analysis of costs and benefits of the SWC measures prior to actual implementation (Chapter 6). Chapter 7 presents the summary of the conclusions of this study. An annex is added in this thesis to guide others who may wish to try out the participatory soil erosion mapping tool, as described in Chapter 6, in areas experiencing soil degradation problems and requiring farmer-led soil erosion assessment and collective SWC planning and implementation at a catchment scale.

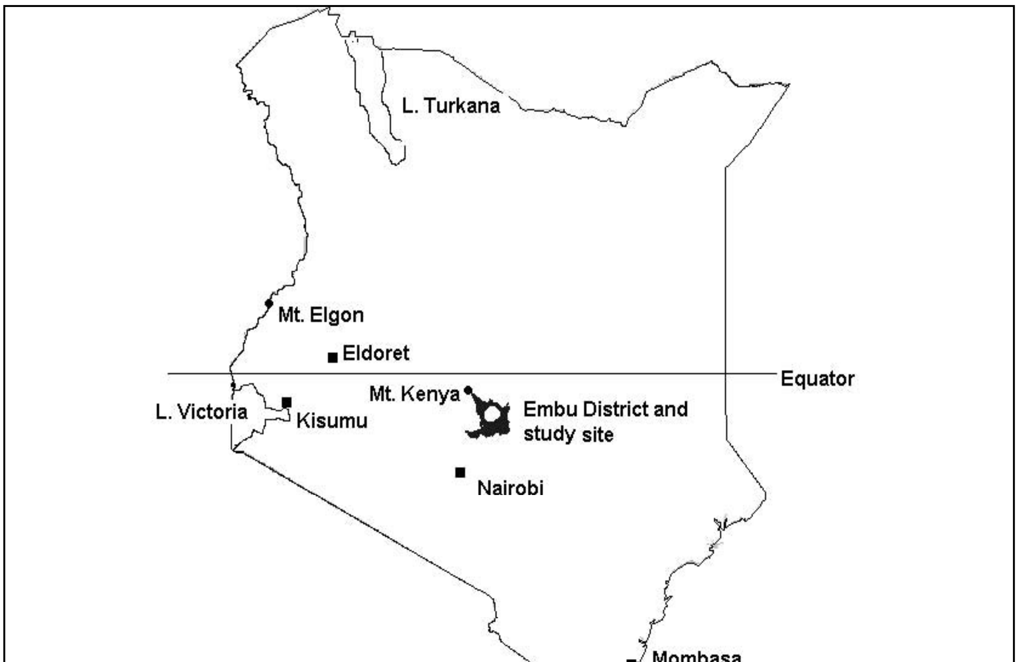

Figure 1. Map of Kenya showing location of study site in Embu District

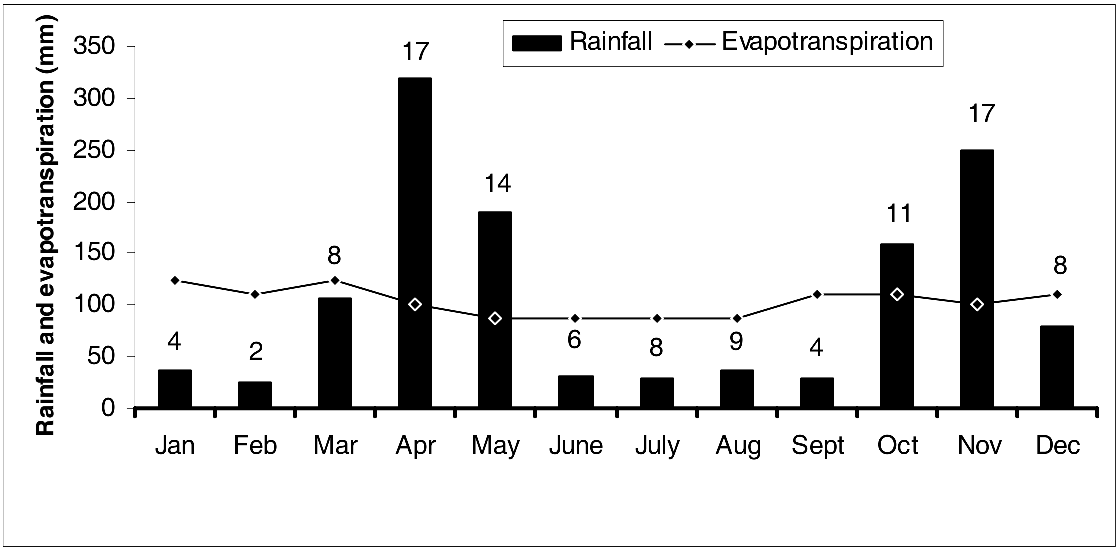

Figure 2. Long-term (25yrs) mean monthly rainfall, evapotranspiration and number of rain-days (shown on top of the rainfall bars) for Gikuuri catchment, Embu, Kenya (Data from Embu meteorological station, No. 63720).

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Chapter 2

FARMERS' KNOWLEDGE AND PERCEPTIONS OF SOIL EROSION AND CONSERVATION MEASURES IN THE CENTRAL HIGHLANDS OF KENYA

Barrack O. Okoba and Jan De Graaff
In Press: Land Degradation & Development

Farmers’ knowledge and perceptions of soil erosion and conservation measures in Central Highlands, Kenya

Abstract

Lack of appreciating farmers’ knowledge and their perceptions of soil erosion and soil conservation measures was the reason for low adoption of recommended technologies. This research was carried out to identify farmers’ criteria in distinguishing farm-types and use these types to evaluate different knowledge and perceptions of soil erosion and existing soil and water conservation measures in central highlands of Kenya. Community meetings and semi-structured household surveys were carried out in a small catchment, with 120 households. Results partly support the idea of using farmer-developed criteria to distinguish among land managers as a farm-type classification. Criteria distinguishing three classes of land managers (good, moderate and poor) were significant with regard to the following land husbandry practices: use of hybrid or recycled seed and use of organic and/or inorganic fertilisers. Farmers were aware of the on-going soil erosion and of several erosion control measures. Majority of farmers preferred grass-strips for soil and water conservation (SWC) measures while they did not recognise agroforestry as a conservation measure. Farmers perceived that SWC measures could successfully increase crop yields, soil-water retention and increase land value. On overall, farmers did not perceive that SWC measures successfully prevented erosion phenomena, given the evidence of on-site erosion indicators. They attributed the continued erosion to high rainfall, steep slopes, lack of maintenance and poorly designed SWC measures. They did not consider poor soil-cover, up-down tillage and tall trees as causes of erosion. Farmers faced several constraints in adopting SWC measures: lack of labour, tools, capital and know-how to construct the measures.

Keywords: *Farmers’ knowledge; Land management criteria; Erosion indicators; Adopted measures; Conservation effects; Adoption constraint; Kenya.*

Introduction

While three quarters of Kenya’s land area falls under arid and semi arid lands (ASAL), characterised by relatively shallow soils and erratic rainfall, the central highlands have a remarkably high agricultural potential (Sombroek *et al*., 1982; Jaetzold and Schmidt, 1983). However, decline in agricultural productivity in the central highlands has largely been associated with high population density, deforestation and intensive cultivation of steep slopes without effective conservation measures (Gachene *et al*., 1997).

The region hosts 75 percent of the country’s population and constitutes one of the upper watersheds for river systems that emanate from the Mt. Kenya forest and drain into the Indian ocean. (Thomas, 1988; Ståhl, 1993). Therefore accelerated soil erosion in the region not only affects the on-site production but also the chain of hydroelectric power schemes in downstream areas. (Westerberg and Christiansson, 1999; Schneider, 2000). Studies have confirmed that the high sediment sources, affecting the hydroelectric reservoirs, are from these highlands and not from the heavily grazed dry lowlands (Schneider, 2000). Because of the severe on-site and off-site degradation trends, the Government of Kenya made efforts to conserve the highlands through agricultural extension networks in the country (Pretty, *et al*., 1995; Kiara *et al*., 1999). But despite the heavy capital and human resources investment, results remain disappointing (Hudson, 1991). Soil erosion levels are still high and farmers are not making much effort to construct and maintain soil and water conservation (SWC) measures (Ovuka, 2000). Some experts think that farmers are ignorant of the seriousness of the on-going soil erosion and are reluctant to changes (Hudson, 1991; Douglas, 1993). Others argue that experts need to seek existing knowledge, cooperation and opinions of farmers before enforcing new recommendations (Hudson, 1991; Shaxson, 1988). By involving them at an earlier stage, the constraints to adoption and their perceptions of the declining soil productivity could be understood better (Kiome and Stocking, 1995; Shiferaw and Holden, 1998).

Mechanisms of developing solutions for soil degradation on agricultural land by research and extension agents need to be re-evaluated. Traditional approaches in undertaking technology development and extension hardly considered farmers' knowledge. For instance, the identification of best-bet technologies for adoption was wholly based on experts' experiences (e.g. Baiya, 2000). Also the categorisation of farmers that were targeted for the recommended technologies was undertaken purely based on experts' criteria. These criteria were set during participatory appraisal exercises (Chambers, *et al*., 1998) and led to segregation of the farmers in categories such as the common interest/problem groups and resource rich or poor (Baiya, 2000). Despite experts' attempts to persuade farmers to control soil erosion, soil degradation continued in full knowledge of the farmers (Wenner, 1989). To clearly understand how farmers perceive the soil degradation and impact of the technologies, a different approach needs to be tried out. A classification of farmers on the basis of how they manage land resources, defined by their own criteria, could provide a better opportunity to learn from different opinions. There is also need to evaluate land managers on the performance of the existing conservation measures and their expectations and experiences. Such knowledge could probably improve fieldworkers' approach when working with farmers.

Therefore research was undertaken in the framework of a participatory project (EROAHI*, 1999) using farmers' knowledge of soil erosion processes with a purpose of improving some components of the procedures used in the current Catchment Approach concept for SWC program in Kenya. The project activities were realised through five main work packages (WP), but only two are hereby mentioned since they are most relevant to the current study:

> WP 1: Identification of indigenous indicators of erosion and sedimentation processes. Undertake characterization of existing soil and water management systems, understand farmers' perceptions of the management systems and evaluate household characteristics.
>
> WP2: Soil erosion and sedimentation at field scale. Take record of farmers' interpretations of erosion impact on soil productivity on basis of their knowledge and perceptions of soil erosion.

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* Is an acronym for a project funded to work in East African Highlands: Development of an improved methods for Soil and Water Conservation planning at catchment scale in the East African highlands, Funds support came through Methodological support to Ecoregional Programs of ISNAR, 1999. Situated in Kenya (Embu, Central Highlands) and Tanzania (Lushoto in West Usambara Highlands)

Therefore this paper intends to provide insight on farmers' assessment of land management types and of ongoing soil degradation through the following objectives:

(i) Identify and evaluate criteria for characterising land managers,

(ii) Assess farmers' knowledge of soil erosion and perceived impact on land productivity and

(iii) Assess farmers' knowledge of the existing SWC measures and identify constraints to their adoption.

Materials and methods

Research area

Because of the high erosion levels, a research area was selected in the central highlands of Kenya, representing the mid-humid climatic zone. These areas are dominated by deep to very deep (160-200 cm) volcanic rhodic Nitosols soils and steep to very steep slopes (15-55%), which are under continuous cultivation with intensive tree-dominated farming systems (Jaetzold and Schmidt, 1983). Widespread soil conservation measures have been implemented in the area but these are in a poor state due to lack of maintenance by farmers who are anticipating for Government assistance. Consequently severe erosion continues to affect farmers' livelihood. The rich top-soils have been washed off by runoff and the remaining sub-soils are generally deficient of available phosphorus and organic carbon and have a low pH (Wanjogu, 2001).

The research was undertaken in a catchment in Runyenjes Division of Embu District (latitude 00^{o} $26^{'}$ S, longitude 37^{o}, $33^{'}$E at 1408 masl) on the eastern footslopes of Mt. Kenya. The catchment covers seven villages of approximately 5 km^2, and is inhabited by 657 farm households. The average farm size is 0.76 ha (ranging from 0.25-3.00 ha) of which about three quarters is under coffee whereas the rest is allocated to food crops and the homestead. The majority of farmers keep some livestock under zero grazing. The main food crops are Irish potatoes (*Solanum tuberosum*), maize (*Zea mays*) and beans (*Phaseolus vulgaris*). Sources for on-farm cash income include coffee, macadamia nuts, *mirraa* or Khat (*Catha edulis*), and dairy production.

The methods of data collection

In order to address the objectives of this study, two surveys were conducted. The first one was a focused community survey involving transect walks and village group meetings in all the seven villages. During the transect walk, a team of researchers and extension officers were guided through the seven villages by the key informants. The key informants were drawn from all villages in the research area. The administrative Chiefs of the two locations where this research was located identified the village leaders whom we requested to appoint 2-3 other full-time committed farmers in their respective villages. These together formed a team of 28 key informants who facilitated the study.

During the second survey, 120 farm households were interviewed using semi-structured questionnaires. The questions were derived from the findings of the community village surveys and transect walks. Three groups of enumerators were used to conduct the interviews, each composed of two high school graduates and one junior extension officer. Prior to conducting the interviews two researchers and three senior extension officers trained the enumerators on how to conduct the survey and how to interpret and translate the questions. We also pre-tested their competence on these issues before pre-testing the questionnaires on a sample of farmers.

Transect walks and village meetings

Transect walks were held in every village as guided by the respective key informants (2-3), whom we also asked to give their opinions regarding soil erosion issues and land management diversity in the area. A checklist of issues that guided our discussions included:

1) Observable erosion indicators (rills, gullies, stoniness, sedimentation etc)

2) Existing SWC measures (their status, compositions on each field, whether there is any preferences of certain SWC types for particular crops, etc.)

3) Slope gradients and land use patterns (dominant slopes and niches of crops and trees, etc.)

4) General land husbandry practices (up-down and across slope tillage patterns, pure and mixed cropping systems etc)

After the transect walks in every village we held a public meeting (*baraza*) with most of the villagers in attendance. During this meetings, in every village, we used the same checklist used during transect walks to confirm gathered opinions.

Community meetings

After completing all transect walks we held a one-day final *baraza* that was attended by about 109 household heads, from the seven villages. During this meeting we presented the preliminary findings of the previous surveys (in each village) and responded to reactions from the audience on the results. But we took the opportunity to establish the consensus knowledge on soil erosion, erosion indicators and SWC measures and what they perceived of them. Since we planned to carry out a household survey to assess individual farmers' opinions on soil erosion and adoption trends of SWC measures, we requested the community members to guide us on the best way to distinguish different farm-types. We wished to rely on their experience of existing differences (patterns) in management of agricultural systems rather than impose our perceptions. The farm-types were categorised, based on certain criteria, into three "land management classes": good, moderate and poor. These criteria described farmers' attitudes and practices in cultivating the agricultural land. The criteria they came up with, after a lengthy discussion, were:

1) Whether he/she has adequate farming tools or has to borrow

2) Preferred direction of tillage (up-down vs. along the contour)

3) Sources of maize seed for planting (hybrid/recycled)

4) Methods of replenishing soil nutrients (farmyard manure and/or inorganic fertilisers)

5) How crop residues from the farm were utilized (forage, mulch or sold)

6) Number of SWC measures adopted by farmers (types and number of strips/earth bunds)

Household survey

After agreeing on a set of criteria for the land management classification we held a meeting with the 27 key informants whom we requested to compile the list of all household heads in their respective villages. Using the list of land management criteria, the key informants then classified only the full time farming household heads into the three land management classes. It was perceived that part time farmers or those who farmed through delegation might not be in a position to respond to the issues to be addressed in the survey. In each land management class, the names of the land managers were numerically numbered in ascending order and using tables of random numbers, 40 land managers were drawn from each class. Questionnaire surveys were then carried with 120 land managers out of the 657 farmers in the research area. The general issues addressed in the questionnaire regarded:

1) Whether farmers were aware that erosion was taking place

2) How farmers detected the on-site and off-site effects of soil erosion

3) How they identified levels of soil loss, soil fertility and crop yields along different slope positions.

4) Level of awareness and adoption of the existing SWC measures, and constraints to their adoption, if any.

Data Analysis

The survey was undertaken from December 2001 through March 2002, with short breaks in between to avoid interfering with peak farming periods (especially planting and weeding). Prior to analysis of farmers' knowledge of soil erosion and SWC measures we triangulated the accuracy of the distinguishing criteria among the land management classes. The interviewees were not informed about the classification on the basis of land management criteria. The household survey data were analysed using a SPSS statistical package version 10.0.5. Descriptive statistics such as frequency distribution, data exploration and cross-tabulation were used. Chi-square tests were used to determine Pearson correlation coefficients in the pairwise analysis of variables.

Results and discussion

Distinguishing farmers on basis of land management criteria

Validity of the distinguishing criteria was ascertained by how it significantly segregated land management classes, as perceived by the key informants prior to the household survey. Though we targeted a sample size of 40 farmers per each land management class, it turned out that a few of the earmarked household heads were not at home during our farm visits or not otherwise available for interviews. Consequently we eventually interviewed 33 good, 46 moderate and 41 poor land managers.

Validity tests of the distinguishing criteria are shown in Table 1, and the response to each criterion is discussed as follows:

1) Borrowing of farming equipment

Results showed that the majority of farmers depended on each other for farm equipment regardless of the land management classes. As such this criterion did not prove sensitive to significantly segregate land managers. This is in contrary to the previously held belief by the key informants that the poor land managers lacked sufficient tools for undertaking farming operation in comparison to the good and moderate managers.

2) Preferred direction of tillage

This criterion was not significantly sensitive in distinguishing land management classes. The results showed that a higher percentage of land managers within each class preferred tillage in up-down direction than along the contour. However, slightly more good land managers undertook along the contour tillage when compared with those in moderate and poor land management classes. Previously it had been perceived by the key informants that digging in up-down slope direction was a practice that was not conservation friendly and only commonly practiced by less conservation-conscious farmers. Asked why they preferred the up-down tillage direction, they stated that manoeuvrability was more difficult when working in across the slope direction, especially on the steep slopes. They also perceived that the crop yields were much higher when crop rows were aligned in the up-down than across the slope. Contrary to the farmers' preferred tillage direction practices, studies from elsewhere have shown that up-down digging in the direction of maximum slope enhanced loss of soil and runoff water (Felipe-Morales *et al*., 1979).

Table 1. Testing sensitivity of distinguishing criteria among the land management classes

Criteria	Attributes	Responses within management classes (%)			
		Good (n=33	Moderate 46	Poor 41)	Sig. level
Borrows farming implements		88	85	80	ns†
Preferred digging direction					ns
	1. Up-down slope	58	65	66	
	2. Across slope	42	33	32	
Uses recommended seed		55	35	20	**
Soil fertility methods					*
	1. Use of FYM only	6	13	27	
	2. Use of inorganic or FYM	33	35	42	
	3. Use of inorganic and FYM	61	52	32	
Major uses of crop residues					ns
	1. Forage	76	72	66	
	2. Sale	0	7	10	
	3. Mulching	24	22	24	
Number of adopted SWC measures		3(±2)‡	3(±1)	3(±1)	

† ns stands for not significant; ‡numbers in parenthesis is the standard deviation from the mean; * Correlation is significant at 0.01 levels; ** correlation is significant at 0.001 level (using Chi-Square tests)

3) Use of recommended hybrid maize seed

This criterion proved significantly (P<0.001) sensitive in segregating the land managers in different classes. There were more good than moderate and poor land managers who planted seasonally the recommended hybrid maize seed. Key informants observed that the alternative option for hybrid seed was the use of "recycled" seed. This was from previous harvested maize crops or sometimes from borrowing planting seed from neighbours (usually not hybrid). Apparently the other farmers depended on "recycled" seed.

4) Soil fertility amendment methods

How farmers improved the soil fertility in their fields was observed to differ significantly (P<0.01) among the land managers. A relatively high proportion of poor land managers used farmyard manure (FYM) as the sole source of improving soil fertility. A high percentage of good and moderate land managers tended to use a combination of organic e.g. FYM and inorganic fertilisers instead of purely relying on either inorganic or FYM fertilizers, as was more common with poor managers. Combining the fertility sources demonstrated the great concern to achieve higher yields when the complementary effects between organic and inorganic nutrient sources are employed. Kapkiyai *et al*. (1999) established that use of organic matter (FYM or maize stovers) alone as fertility source gave much lower maize yields than when both the organic and inorganic sources were combined.

5) Major uses of crop residues

The results indicated that use of crop residues for livestock feeding and for mulching were common practices across all land management classes and thus not a sensitive criterion (not significantly different). Livestock, particularly goats, sheep and cattle in the research area are *zero* grazed and occasionally tethered within the farm. Therefore it was not a likely practice for farmers to sell maize stovers since results showed that only 10% of poor and 7% of moderate land managers admitted that they sold crop residues for cash income.

6) Number of adopted SWC structures

Good managers were perceived to be those who had attempted to control soil erosion or runoff by any method they deemed workable. This was the hypothesis at the beginning of the survey as set by the key informants. Therefore during the survey, all feasible SWC structures were counted on all the farms visited. Results did not differ across the land management classes. The mean number and standard deviations showed a trend that implied that this was not a sensitive criterion. Number of SWC structures on the farms of good land managers ranged between one and five and for both the moderate and poor managers between two and four.

It is necessary to state that the key informants' criteria to distinguish land managers were interesting and new despite poor statistical proof to confirm farmers in their respective categories, as perceived by the key informants. It can also be observed that the farmer-generated criteria tended to describe attitudes and practices rather than highlighting their production problems or wealth status. These criteria clearly deviated from the conventional criteria mentioned in most studies when considering farmers' land management capabilities such as the age and gender of household, off-farm income, size of household, remittances and size of the farm (Bewket, 2003). There is however need to undertake further study to see whether this land management classification approach could be applicable in other areas.

Besides assessing how the criteria distinguished among the farmers in the respective land management classes the farmers' knowledge and perceptions of the on-going soil erosion and its effects on crop productivity were examined.

Farmers' knowledge and perceptions

Awareness of soil erosion and its effects

This research revealed that 98% of farmers experienced soil erosion on their fields regardless of their land management classes and in spite of the existing SWC structures on most of their farms.

Farmers were aware of soil erosion processes, which they defined as "carrying away of soil or removal of top-soil by water or loss of soil triggered by human activities". Farmers' perceived reasons for continued soil erosion processes were listed and scored (Fig. 1).

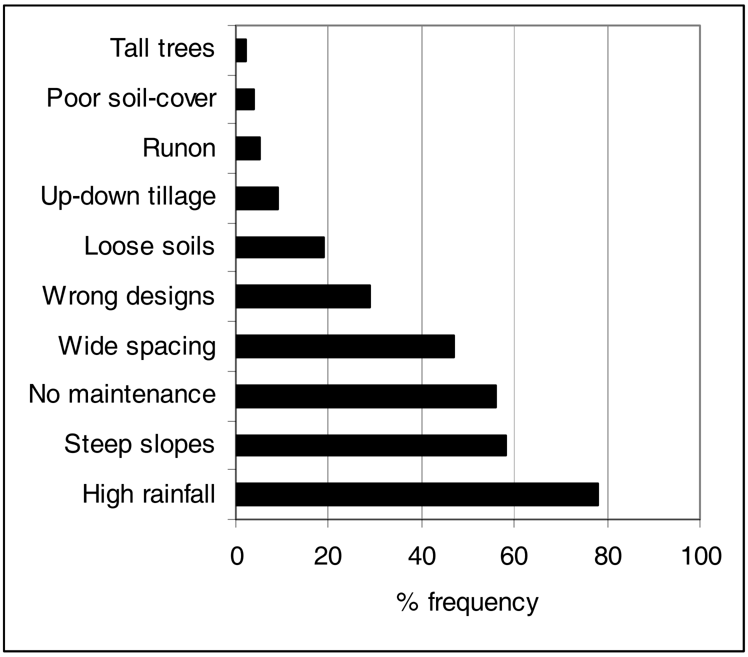

Figure 1. Perceived reasons for continued soil erosion despite the existing SWC measures (Farmers were allowed to mention as many reasons as possible)

Most farmers mentioned high rainfall and steep slopes as the major causes to soil erosion. Other causes of erosion were lack of maintenance and widely spaced SWC structures. Most farmers did not associate tall trees, up-down tillage practices (given the steep slopes), poor soil cover and runon with the on-going soil erosion. The evidence of the on-going soil erosion was demonstrated with identification of several on-site erosion indicators (Table 2, left hand side). The most often observed indicators were rills, root exposure and sheetwash. Relatively few farmers observed splash pedestals and stoniness. Despite the variation in observing erosion indicators, most farmers associated their development with high rainfall, runoff and steep slopes (Table 2, right hand side). Results also showed that farmers attributed appearance of red soil, stoniness and splash pedestals to factors other than the impacts of rainfall and runoff only. These findings do confirm that farmers are aware that erosion is damaging their fields by factors they cannot control effectively. The farmers' perceptions are in some way in agreement with Sierra Leone farmers who associated the erosion problem on their land with high rainfall, steep slopes and lack of vegetation (Millington, 1987 cited by Morgan 1996).

Field observation showed that erosion indicators were more widespread on steep and gentle slopes than on very steep slopes. A low presence of erosion indicators on very steep slopes was, in most cases, the result of abandoned field after longterm damage by overland flow from upstream fields that were equally not conserved adequately.

Table 2. Percentage distribution of the observed erosion indicators and their perceived causes, based on 120 respondents

Erosion indicators	No. of observed indicators	Perceived causes (%)				
		Rainfall	Runoff	Steep slopes	Loose soils	Others
Rills	112	55	15	12	5	13
Root exposure	66	18	42	14	11	15
Sheetwash	65	42	14	3	14	27
Red soils	52	8	19	8	0	65
Gullies	36	75	14	3	3	5
Sedimentation	31	13	42	7	0	28
Splash pedestals	28	32	11	0	14	43
Stoniness	10	14	21	14	0	40

Effect of erosion on productivity

To gain further insight in farmers' knowledge of land productivity and how it was affected by erosion, we interrogated farmers on what criteria they used to determine good soils. Prior to the household survey, during the final *baraza* meeting farmers stated that certain critical criteria were applied when bargaining for sale or purchase of land, or when apportioning land among wives or sons. In this study only three land suitability criteria were considered i.e. soil erosion status, level of soil fertility and crop yield production potential. Though there was no significant correlation difference between land management classes and each suitability criteria, we show the scoring of the total sampled population's perceptions for each slope position (Table 3). In the study area most field holdings tended to stretch from the top of the ridgetop to the valley bottom through the steep or very steep hillslope segments. Therefore farmers were in a position to express their perceptions for each slope position.

Results indicated that farmers knew that the rate of soil loss and level of soil fertility were related, which consequently determined the crop yield potential on any landscape positions (Table 3). The majority of farmers perceived that steep and very steep slopes were landscape segments with high risk of soil erosion and low levels of soil fertility resulting in low crop yields. But with low rates of soil loss experienced on flat ridge-tops and in the valley bottoms, soil fertility tended to be high and hence higher crop yield potential. Gentle slopes clearly ranked fairly showing moderate yield potential.

The farmers' description is in agreement with scientific knowledge that acknowledges effects of slope steepness on land productivity (Lal, 1994; Morgan, 1996; Rockström *et al*., 1999). Other scientific experiments agree with farmers' observation (Daniels *et al*., 1985; Stones *et al*., 1985; Rockstöm *et al*., 1999). These reports show low yields of maize and millet on fields located on steeper slopes that are often severely eroded. The yield reduction was attributed to decreased availability of water holding capacity on severely eroded fields. The farmers' knowledge is also in agreement with findings by Steiner (1998) on farmers in Rwanda who associated soil suitability with slope position. Steeper slopes generally had shallower soils whereas on plateau and footslopes fine textured soils dominated, implying soils of high fertility.

Table 3. Perceived scores on different land suitability criteria by slope position (N=120)

	Land suitability criteria								
	Soil loss rate			Soil fertility			Potential crop yield		
Slope position	high	mod	low	high	mod	low	high	mod	Low
	%			%			%		
Very steep (> 32%)	**95**	1	3	0	2	**82**	1	1	**97**
Steep (15-32%)	**86**	9	3	1	7	**88**	2	13	**83**
Gentle (6-15%)	3	**75**	18	13	**82**	3	12	**82**	2
Ridgetop/flat (<6%)	3	6	**85**	**91**	6	0	**89**	5	3
Valley-bottom	3	15	**68**	**85**	10	3	**81**	9	7

Note: Notice the trend of the highlighted percentages; The scores do not total to 100 %, because some farmers scored for more than two criteria levels and hence not included in this scoring

Awareness of soil and water conservation measures and adoption constraints

Awareness of conservation systems

There were differences in level of awareness and adoption of SWC measures among farmers in general but no significant correlation was found with land management classes. However, Figure 2 shows general trends of known and adopted SWC options in the study area. By known SWC measures we imply that the farmer had knowledge of such a conservation option whereas by adopted SWC measures we imply that the farmer had installed such a conservation option either by own choice or through Government support. Bench terraces, grass strips, *fanya juu* (made by throwing-up excavated soil on the upper part of the trench), mulching and trashlines were widely known but the level of adoption varied greatly. Grass strips (Napier grass) were the most widely adopted SWC measure followed by bench terraces and mulching. Despite its wide fame, *fanya juu* measures were only adopted by a small percentage of the interviewed farmers. Least recognised as a SWC measure were the woodlot and agroforestry practices.

The multipurpose role and benefits from grass strips could explain the high adoption rate. Grass strips serve as a main source of fodder for livestock as well as a good filtering hedge against runoff water. It is also used to stabilize risers of *fanya juu* terraces. Farmers would tend to go for short-term return systems (mulching and grass strips) rather than labour intensive conservation systems (Thomas, 1988). Awareness and adoption of bench terraces and *fanya juu* measures can be linked to colonial legacy whereby these measures were adopted by coercion (Wenner, 1981; Ståhl, 1993; Kiara *et al*., 1999). Interestingly, despite the high-density tree-crop integration system observed in the research area and in the whole of Mt. Kenya region, the results of this study do indicate that the contribution of trees to SWC was not recognised by farmers.

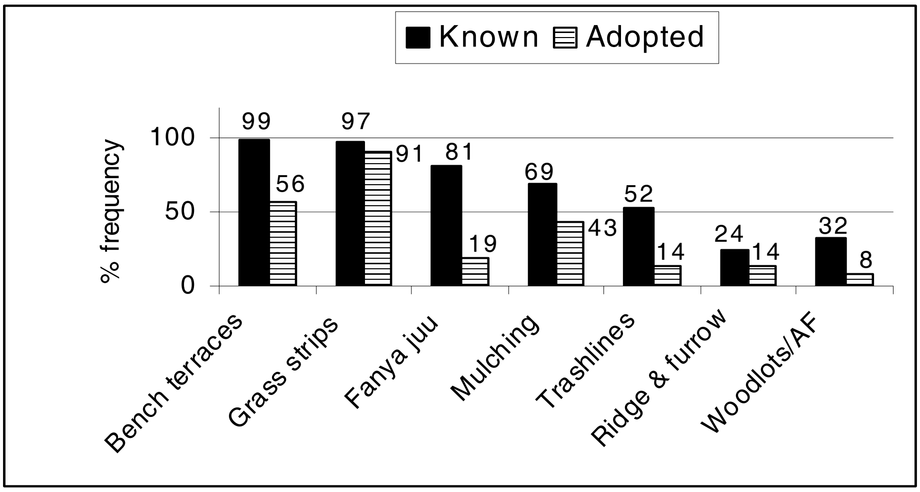

Figure 2. Level of known (aware of) and adopted (already installed) SWC measures

Tree planting has always been promoted foremost as a source of construction timber and fuel-wood but not for soil erosion control, given that their dominant niches are on farm boundaries. Farmers viewed trees as a great source of farm cash income, given the restriction to logging in Government forests. Elsewhere, in the central highlands of Kenya, Tyndall (1996) found that farmers were not willing to adopt trees within cultivated field as SWC measures, except on boundary niches, primarily because they were good life fences which ensured land tenure security. These farmers argued that trees within the cropped area caused nutrient competition and soil erosion, due to the runoff water generated under tree canopies.

Perceived effects of SWC measures and constraints of adoption

1) Effects of SWC measures on productivity parameters

Given that the importance of SWC measures in controlling soil erosion was not a new concept to the farmers in the research area, we wished to evaluate the effect of SWC measures on soil productivity and the expectations farmers had on installed SWC measures. The opinions of farmers on these issues did not significantly differ among land managers. The majority of farmers perceived that SWC measures increased crop yields, improved soil fertility and improved soil-water retention capacity of the soils (Table 4). Due to a high land tenure security enjoyed by almost all Kenyans, and particularly in the high potential regions of the country, the tendency to mortgage land or sell a portion of land were very common. Banks and other financial lending agencies estimated value of land on basis of many on-farm attributes, which included farm house(s), trees, and agricultural potential of the land under consideration. During this research we enquired whether installed SWC measures did increase the value of land, though we knew financial institutions did not consider them as such. But we still wished to know whether farmers ever considered the time and financial investment costs in construction of SWC structures when selling land. Only 46% of farmers recognised that SWC on a farm could or did enhance land market value. But very few farmers believed that SWC measures could indeed assure long-term productivity of the land. This implies that farmers were likely to invest in simple and cheap short-term benefit measures rather than to go for the recommended mechanical structures such as bench terraces and *fanya juu*. Because of the top-down enforcement to adopt mechanical SWC measures that were not properly implemented, farmers had formed an opinion that conservation measures were less successful in soil erosion control. As such, 96 percent of farmers perceived that conservation measures were incapable of preventing (or stopping) soil erosion phenomenon, based on the performance of the SWC on their fields, despite the positive perceptions they had for the SWC measures.

Table 4. Farmers' perceived impact of SWC measures

What SWC can influence	Yes (%)	No (%)
Increased crop yield	82	18
Improved soil fertility	56	44
Improved soil-water retention	50	50
Add market value of land	46	54
Assured long-term productivity	13	87
Prevent soil erosion	4	96

2) Constraints to adoption of SWC measures

Farmers listed several constraints encountered when adopting SWC measures. It was investigated how farmers who had already adopted some kind of SWC measures on their fields experienced these constraints. Mainly to establish types of constraints experienced by farmers with a different number of adopted SWC measures (Table 5). Generally, the main constraints were lack of money and insufficient labour force to undertake conservation measures. The next important constraints were lack of tillage tools and poor knowledge about the benefits of SWC measures. Land tenure, construction know-how, size of farm and women-headed households were least recognised constraints to the adoption of SWC measures, against popular beliefs (Khasiani, 1992; Ståhl, 1993; Tenge, *et al*., 2004). In particular, the women-headed households were not regarded as a hindrance to adoption of SWC measures given the emphasis by SWC program donors on gender considerations when designing and planning for SWC measures (Pretty *et al*., 1995). Also level of education demystifying traditions that biased against women in Africa has improved women participation in SWC programs (Pretty, *et al*., 1995). Therefore the cause for the current low motivation to increase and maintain the number of SWC measures might be due to adoption constraints, listed in this study, and others possibly not identified. With regard to land tenure security, most farmers in the study area have title deeds but still those who did not have were assured of security of ownership from the head of the family. Hence the lack of it would not hinder installation of SWC measures if one wished to do so. Studies in the Philippines and in Ethiopian highlands have shown that security of ownership was not always a necessary condition to adopt SWC measures as factors of kinship, rental contracts and share-cropping arrangements improved investment decisions (Lapar and Pandey, 1999; Kidanu, 2004).

Table 5. Observed constraints to adoption of SWC measures by farmers, and in relation to the number of SWC measures adopted.

		Scores by number of SWC measures adopted* (%)				
Adoption constraints	Overall score (%)	1 (n=16)	2 (n=30)	3 (n=41)	4 (n=17)	5 (n=9)
Lack of money/capital	90	75	90	95	82	89
Lack of labour	70	81	83	81	47	33
Lack of tillage tools	46	44	60	52	35	33
Benefits not known	41	44	23	44	41	56
Lack of construction know-how	26	31	23	29	12	22
Land tenure insecurity	11	6	17	12	12	0
Small farm size	13	6	23	17	6	0
Women headed-households	8	0	7	10	6	11

*Types and numbers of adopted SWC measures strips may have included single or combinations of any of these measures: *Fanya juu*, bench terraces, grass strips, trashlines, mulching and ridge & furrow.

One other important finding from this study was that some of the listed adoption constraints (Table 5) tended to be less of a problem with increase in number of SWC measures adopted. This was particularly noted with regard to lack of labour and tillage tools. Possibly because the more SWC measures a farmer had, the more effective erosion was controlled. And this lead to higher productivity and higher cash income and help to solve other typical constraints experienced by small-holder farmers. Similar constraints have been observed elsewhere by others (Tenge *et al*., 2004).

Conclusions

Farmers had very specific criteria for distinguishing different classes of farm-types or land managers. Their criteria were based on individual attitudes and practices in land management rather than on wealth or problem oriented aspects. Most sensitive of the listed discriminating criteria were land husbandry practices such as source of planting seed and soil fertility enhancement methods on which basis good, moderate and poor land managers could clearly be distinguished. Though the rest did not statistically show clear discriminating influences the farmers believed that they were of essence in their circumstances. These criteria are quite different from the approaches employed by scientists and agricultural extension agents during participatory appraisals in rural communities. They tend to consider criteria like size of the household, level of education, off-farm income, number of livestock, farm size and land tenure when formulating technologies for target farmer groups. However we propose a further development of this approach where farmers would be allowed to identify criteria that they perceive best suited to their circumstances.

It was established that farmers were aware that soil erosion was damaging their land. Ninety-eight percent of farmers experienced soil erosion, a phenomenon they related to the widespread on-site erosion indicators. Rills were most often mentioned, followed by root exposures, sheetwash (runoff flow paths) and change of soil colour to red (red soils). They attributed the formation of these indicators to factors as: high rainfall, runoff from upslope fields, steep slopes and poorly designed or ineffective SWC measures, which they find themselves incapable to change. They however, did not see any linkage between the on-going erosion with tall trees, poor soil-cover and the up-down tillage practices. An observation that is contradictory to scientific evidence (Felipe-Morales *et al*., 1979).

Farmers attributed soil fertility levels and crop yield potential to slope position, a knowledge the household heads employed when identifying suitable fields for certain crops and sharing out land among household members. Fields on flat and gentle slopes, and in the valley bottom areas were perceived to have highest potential for crop production. Fields on steep and very steep slopes were perceived to be eroded hence the likelihood of not realising high crop yields. Farmers perceived that increased crop yield could be realised, among other husbandry practices, through implementation of SWC measures. In addition to increased crop yield, SWC measures were perceived to improve soil fertility, soil-water retention and even increase the market value of that land. Apparently farmers were knowledgeable about various SWC measures but implemented a few of them. Low appreciation of the widespread agroforestry systems in the research area as a soil conservation measure implied that farmers were more interested in the tree by-products (woodfuel and construction timber), than its scientifically perceived effects on soil and water conservation. Even though farmers had knowledge of many types of SWC measures, constraints to ensure widespread adoption were still being experienced. The most important constraints were lack of capital and tools, labour shortage and construction know-how.

This research has shown that farmers in this area had quite specific perceptions of land management aspects, and constraints to adoption of SWC measures. Continued efforts should be made to involve farmers in farm type classification to be used for targeting land management interventions.

Acknowledgements

Financial support for this research came from the Ecoregional Fund to Support Methodological Initiatives managed by the International Services for National Agricultural Research (ISNAR) at The Hague. We wish to acknowledge the contributions of Alterra Greenworld Research Institute – Wageningen (The Netherlands) and the Kenya Agricultural Research Institute in project management during the research period. Personal involvement of the Ministry of Agriculture staff, particularly Mr. Mwarasomba Lincoln (Nairobi) and Mr. Jackson Nyaga (Runyenjes-Embu), are highly appreciated. All the farmers of Runyenjes Township Location are much appreciated for their time during the interviews, the *barazas* , and specifically our key informants are thanked for their time and knowledge. Support during the surveys and data entry from Mr. Leonard Musiega and Mr. Charles Mugo Rimui, both of EROAHI project, are highly appreciated.

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Chapter 3

FARMERS' IDENTIFICATION OF EROSION INDICATORS AND RELATED EROSION DAMAGE IN THE CENTRAL HIGHLANDS OF KENYA

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Submitted to: CATENA (2004)

Farmers' identification of erosion indicators and related erosion damage in the Central Highlands of Kenya

Abstract

Most soil and water conservation planning approaches rely on empirical assessment methods and hardly consider farmers' knowledge of soil erosion processes. Farmers' knowledge of on-site erosion indicators could be useful in assessing the site-specific erosion status before planning any conservation measures. The aims of this study were to identify erosion indicators based on the farmers' knowledge and assess relevance of these indicators in estimating soil erosion damage. Household, community and key informant surveys were carried out in an agriculturally high potential smallholder farming system in central highlands of Kenya. Survey data were assessed based on consensus views, percentage frequency and descriptive statistics. Eleven erosion indicators were identified and described in local language, and their causes outlined, which closely agreed with scientific knowledge. Indicators were not only distinguished between current (splash pedestals, rills, sheetwash, sedimentation, root exposure) and past (stoniness, red soils, gullies, loose soils) but classified into erosion rates of high, moderate and low. Current and past erosion indicators were distinguished by the duration of rainfall event(s). Current indicators were perceived to be reversible in the sense that they were frequently obliterated through seasonal ploughing and weeding. They were therefore assumed to cause less soil damage thus signifying low to moderate soil loss rates. But continuous neglect of current indicators led to formation of past (irreversible) erosion indicators. Soils with such indicators were not easily restored to food crop production instead converted to other enterprises like stone crashing for construction materials and growing of *mirraa* (*Catha edulis*). The spatial distribution of the erosion indicators along the hillslope was described fitting the influence of runoff velocity with increasing gradient and slope length-steepness factors. Steep slopes were more severely damaged than the gentle and flat slopes. Farmers illustrated how relative erosion indicator weights: an index of soil damage, could be used to identify more severely eroded portions of fields or hillslopes that needed conservation attention. This approach did show that severity of erosion status or extent of soil damage by erosion was dependent on the number and type of erosion indicators, and the total weight index of on-site erosion indicators. Consequently, widescale adoption of farmers' erosion indicators in estimating the rate of soil loss or soil erosion status might be a rational approach by which land-users would undertake self evaluation of erosion status on their own farms. By this way, they would probably get convinced to implement conservation measures without external enforcement.

Keywords: *Farmers' indicators; Current erosion indicators; Past erosion indicators; Soil erosion rates; Erosion weights; Kenya*

Introduction

The Central Highlands of Kenya have a high potential for agricultural production, though it represents only 18% of the country's total area. The landscape is characterised by abundant rainfall, steep slope gradients and fertile volcanic soils (Ståhl, 1993). Lately the region is experiencing severe land degradation problems that are emanating from the demands of the growing human and livestock populations (Minae and Nyamai, 1988). This environmental situation not only undermines the agricultural production capacity but also threatens the future of the hydro-power electricity generation (Ståhl, 1993; Thomas et al., 1997; Kitheka, 2000; Schneider, 2000).

Because of the widespread land degradation, following the 1972 UN Conference on Human Environment at Stockholm, Sweden, the Government of Kenya has continued to reinforce formulation of policies and strategies that would address among others the problems of soil erosion by water (Ståhl, 1993). These threats compelled the Government to use incentives and forced-labour approaches to ensure that soil and water conservation (SWC) measures were constructed (Wenner, 1989; Thomas *et al.*, 1997). Despite the vigorous campaigns farmers neglected the maintenance of the constructed SWC measures even within their own farms. Hence adoption of the promoted SWC measures remained dismally low even with all the resource investment in the widely known catchment approach concept of the extension program (Ståhl, 1993; Pretty *et al.*, 1995).

Given the low adoption of SWC measures, small-holder farmers have continued to rely on depleting natural land resources for their living. Although most farmers are aware that erosion is the primary cause of soil quality depletion yet not much interest is shown for SWC measures to sustain soil productivity. Nor do some farmers draw linkage between specific erosion features and loss of soil productivity on their farms; a surprising mismatch to scientific knowledge (Wenner, 1989; Kiome and Stocking, 1995; Östberg, 1995). However, previous approaches made no positive changes with respect to the rate of land degradation, primarily because they undermined farmers' views and perceptions of the land degradation and SWC planning. Using experiences from Lesotho and USA, Osterman and Hicks (1988) and Wenner (1989) showed the need for projects to work with farmers that are interested in carrying out conservation works. Moreover, when adopting the farmer-perspective approaches, it is important to build on their experiences. This reinforces the realism of how farmers perceive their interests, how they understand the way erosion impacts on their lives, and how they value the costs and benefits of any measures of conservation that may be promoted (Wenner, 1989; Stocking and Clark, 1999). Recent diagnostic participatory approaches are increasingly showing that farmers clearly perceive and articulate differences in the levels of soil fertility on their farms (Brouwers, 1993; Murage *et al.*, 2000).

Similarly it should be possible to use the experience and indicators of farmers for identifying, the areas in the landscape that are most degraded by soil erosion. Quick and simple scientific quantification methods for soil erosion rates do not exist. Until now, soil loss evaluation procedures have heavily relied on established expensive and time-consuming methods notably runoff plots, modelling and interpretation of aerial imageries, amongst others (Lal, 1994). Potentially, actual soil losses could be quantified using farmers' indicator of soil erosion (Stocking and Murnaghan, 2001). Warren (1991) and de Villiers (1996) demonstrated how farmers' knowledge could be employed by researchers to correlate known scientific soil nutrient thresholds with farmers' indigenous soil fertility indicators. They recommended the use of farmers' judgement as an appropriate tool in undertaking rapid assessment of soil fertility and crop performance without needing field trials. The aim of this study was to identify farmers' indicators for soil erosion in a hydrological catchment on the slopes of Mount Kenya, and assess the indicators' relative importance to soil erosion damage.

Materials and methods

Site description

To address the aims of this study, a representative site in the highlands of Kenya was identified on the eastern footslopes of Mt. Kenya in Embu District, Runyenjes Division. The study was carried out in Gikuuri catchment, a small hydrological catchment (approx. 500 ha) covering seven villages (latitude 00^{o}26'S and longitude 37^{o}33'E) at an elevation ranging from 1302-1500 m. It has three major river tributaries in the upper parts that drain into a perennial single river at the catchment outlet. In general, the landscape tends to have two major slope segments. The upper segment is convex shaped consisting of the flat ridgetops and gentle slopes (2-15%) and the lower segment, which is concave shaped, consists of steep (15-32%) and very steep slopes (>32%). Right below the lower slope segment is the valley bottom. There are obvious slope breaks between the upper and lower slope segments. These define both the slope steepness and slope lengths. The upper slope segment tends to have shorter slope lengths (10-45 m) than the lower slope segment, which is generally longer (83-180 m).

Soils have developed from mixed volcanic rocks, which include phonolites, trachytes and tuffs as parent material. The soil texture composition has high clay content (more than 75%) and hence classified as clay soils, also known as *kikuyu* red soils. They are generally well drained and deep to very deep (>160 cm) but most of its topsoil has been severely eroded (Wanjogu, 2001). According to a detailed soil survey map, four soil types (according to FAO classification) cover the study area variably depending on topographic positions. On gentle to steep hillslopes typical soil types are rhodic Nitosols, haplic Acrisols and chromic Luvisols whereas on very steep hillslopes a combination of chromic Luvisols and Cambisols are dominant (Wanjogu, 2001). Valley bottoms are however occupied with soils developed on colluvium and alluvium and derived from various rocks. These soils are classified as dystric Gleysols and Fluvisols. In general, the whole landscape is suitable for agricultural production despite the low soil fertility due to severe land degradation.

The climate is humid, characterised by wet and dry months with a longterm mean annual rainfall of about 1270 mm, and mean maximum and minimum temperatures of approximately 25^{o}C and 15^{o}C, respectively (data from Embu Meteorological Station No. 63720 at Kenya Agricultural Research Institute (KARI)-Embu, located 17 km from the study site). The rainfall regime is bi-modal and distributed over the long rains (LR) and the short rains (SR) seasons. The LR season is experienced from mid March to late May with precipitation of about 594 mm (i.e. 47% of the annual rainfall), while the SR season comes from mid October to early December with a precipitation of about 487 mm (i.e. 38% of the annual rainfall). The remaining 15% of the annual rainfall is experienced as showers between the two distinct rainfall seasons.

The land use in the study area is characterised by small-holder subsistence agriculture. Average farm household land holdings ranges from 0.25 – 3.00 ha. About three-quarters of the land area is allocated for cultivation of food crops, dairy cattle keeping (under zero grazing system) and an area for a homestead, whereas the rest of the land is put under cash crops. Food crops are maize (*Zea mays*), potato (*Solanum tuberosum*), banana (*Musa,* Species) and beans (*Phaseolus vulgaris*) while cash crops include coffee (*Coffea arabica,* var.), macadamia (*Macadamia integrifolia* var.) and khat (Kat) or *mirraa* (*Catha edulis*). The latter is a shrub plant that is gaining popularity in the region, especially among the younger farmers because of its ready local and international market. Valley bottoms are mainly utilised for cultivation of vegetables both for cash income and household consumption.

Community and household surveys

Two types of surveys were carried out in all the seven villages that form the study area, from December 2001 to March 2002. The survey team consisted of researchers, extension officers from the Runyenjes Division, and the representative village key informants. These included village headmen and 2-3 other village members (male and female). Overall, there were 28 key informants from the catchment area to assist in this study.

The first survey, comprising transect walks and farmer groups discussion sessions, focussed on the farmers' knowledge and capability to identify existing erosion indicators on the cultivated landscape. Transect walks were carried out in the morning while farmer group discussions in villages were held in the afternoons. Using a checklist of land husbandry practices and general aspects of land degradation, transect walks were conducted on village-by-village basis. During the walks, researchers and extensionists observed and took note of the level of land degradation and types of erosion indicators associated with water erosion. Occasionally, *adhoc* open-ended interviews were carried out with farmers who were met along the transect path. During the afternoon meetings, attended by between 33 and 90 farmers per village on various days, farmers enumerated the known erosion indicators. They also described appearance of each of the indicators in their fields and their causes. Other issues discussed in these meetings included: categorisation of indicators into those that were observable either immediately after a rainy season/a rainfall event (i.e. current indicators) or as a result of long-term erosion effects (i.e. past indicators). In another separate meeting, the key informants analysed all the erosion indicators generated by the village groups, to establish the final consensus list of erosion indicators for the study area.

The second survey was carried out to assess individual household's opinions on identification and perceptions of typical soil erosion indicators on their fields. It consisted of a formal interview, using semi-structured questionnaires on a randomly selected 120 households of the 657 family households in the study area. The selected households represented three farm-type classes (i.e. good, moderate and poor) with each class represented by 40 households. The farm-types were distinguished on basis of how individual farmers carried out farming operations (up-down/across slope direction), soil management practices (use of inorganic and/or organics, none), type and source of planting seed used, and number of SWC measures on their fields. The 27 key informants set these criteria, hoping that they would reveal the existing differences in knowledge, perceptions and management patterns among the farmers. The issues covered in the questionnaire survey forms included extent of awareness of the on-site impact of soil erosion, perceived causes to development of these erosion indicators, how the farmer distinguished between different soil loss levels and soil damage, and distribution of these indicators along the slope position.

Three groups of enumerators were used to conduct the interviews, each composed of two high school graduates and one junior extension officer. Prior to conducting the interviews two researchers and three senior extension officers trained the enumerators on how to conduct the interviews to ensure that farmers' responses were realistic and purely based on their farming experience. The enumerators were also trained on how to interpret and translate the questions; from

English to the local language (*Ki-Embu*). We also pre-tested their competence on these issues before pre-testing the questionnaires on a sample of farmers.

The community views were summarised according to group consensus while the structured household survey data was analysed using percentage frequency, cross tabulation and descriptive statistics of the SPSS version 10.0.5 for windows.

Relative importance of erosion indicators to soil damage

After community and household surveys, a further meeting with the 27 key informants was held. The aim of this meeting was to estimate erosion severity for each erosion indicator. We asked them to use their farming experience to decide which of the listed indicators relatively implied a more severe level of soil damage than the other. They used a pairwise matrix analysis approach to rank erosion indicators according to their perceived erosion severity.

The analysis involved comparing one erosion indicator against all others, by consensus the key informants decided between the two indicators, which was perceived to imply greater erosion damage than the other. Once all the indicators had been contrasted, the frequency or the number of times the indicator was superior over others was recorded against it. The relative importance of indicator damage to the soil was computed and expressed as a weight, which is a ratio of frequency count for individual indicator to the total counts for all indicators. This weight could be used in determining the site-specific erosion damage especially in cases where multiple erosion indicators were unequally distributed on a given field or hillslope. Different scenarios on how the assigned weights could be used to assess the extent of soil damage was illustrated to the farmers after carrying out transect walks, across the neighbouring fields, with an aim of noting the existing erosion indicators.

Results and discussion

Erosion indicators and perceived causes

Farmers were aware of many types of erosion indicators, which they observed during their daily farming chores. However this awareness did not differ across the three farm-type classes (land managers), as perceived by the key informants, hence these results represent the views of the total sampled population (N=120). Farmers identified a consensus list of erosion indicators, which they clearly described in local language. They also outlined what they perceived as the determining factors or causes leading to the development of these indicators (Table 1). Eleven common erosion indicators were identified in the research area. Farmers described them as follows:

1) Rills (*Tumivuko*): They are observed to develop immediately after a rainfall event commencing in the early part of the rainfall season. They are continuous or discontinuous and tend to start at about 3m from the rigde/crest divide or where road runoff empties into a field. The channels are also found to start at the base of the maize stock or tree trunk. They are prone to soils that have fine to moderate soil tilth. They

form a network of branching channels, depending on amount of rain and roughness of the ground surface.

2) Sheetwash (*Muguo*): The local language name means literally a flow path or sheet of runoff that flows over the soil surface, leaving smoothed surface and has sediment cover that shows the lines of the flow. The flow paths can either be narrow or wide and sometimes long or short depending on slope and encountered obstructions during the rainfall event.

3) Sedimentation (*Gukunikuo*): The local language name means literally “covering or burying”. It describes the effect the surface runoff water, through sheetwash or rill features, leaves when it comes against a barrier, depression or lacks transport capacity. Observed at end of rill channels as sediment fan. Deposited load could include uprooted plants and “foreign or new” soils. Where sedimentation was observed some farmers mentioned improved soil fertility whereas others mentioned lower fertility conditions. The former is when the deposits are dark in colour leading to improved yields whereas the latter (infertility) occurs when the material consisted of red or stony soils overlaying the darker soils.

4) Red soils (*Ithetu itune*): This indicator describes the colour of remaining soil; turning from dark to red. This was an indication that dark top soil had been removed by water erosion. They also referred to such soils as infertile or had grown “old” meaning the topsoil had gone leaving sub-surface soil layers, which were no longer producing high yields.

5) Root exposure (*Kuicirurio tumiri* or *miri*): Literally meaning seeing roots. This happens when the soil around the stem of the plant was removed. Exposed roots caused maize or trees fail to stay in an upright position, forcing them to bend due to canopy weight or force of wind and could also wither off. Plants, especially legumes, with their superficial roots exposed were considered to be easily uprooted by sheetwash or overland flow.

6) Stoniness (*Tumathiga*): This means small stones lying loose on the soil surface at different densities. This phenomenon is also referred to as stony or gravel soil, or stone mulch/layer. The stoniness are exposed on soil surface after the dark top-soil and the red sub-soil layers have been eroded. In high stoniness conditions tillage using a hoe was impractical, instead machetes were used (especially for digging and weeding).

7) Rock exposure (*Mathiga*): Unlike the stoniness, this indicator means sparsely scattered rock outcrops. Farmers observed this in places with shallow soil depths, which once washed off by water erosion the rocks were exposed. Some farmers said that rocks were “growing” though they hardly noticed any significant increase of rock “growth” in their generation.

8) Gullies (*Mivuko minene*): Literally meaning big or large channels, differentiated from rills by their sizes. Farmers distinguished gullies from rills when a child of seven years old couldn’t jump across. They were more common along the footpaths (aligned along the slope direction) and in fields adjacent to roads or home compounds with tin roofed houses. But also identified in fields lacking SWC measures and either with few or widely spaced/wrongly designed SWC measures.

9) Splash pedestals (*Matata*): Describes the holes/craters and pillars of soil that are observed underneath tree canopies after a rainfall event. Plant twigs/stalks or small stones capped the soil pillars. As a result of raindrop impact on bare soil surfaces, craters developed even outside tree canopies.

10) Loose soils (*Muthetu muvuthu*): Literally means soils without strength or "weightless", and could be lifted by water or wind easily. These soils are neither red nor dark in colour but merely a transition between the two soil colours. The condition was realised when *insitu* topsoil was removed by water erosion. This indicator presents poor soil structure and low soil-water retention capacity since plants tended to quickly wither at the onset of dry periods.

11) Broken SWC structures (*Kuomomoka kwa mitaro*): Referred to gaps or breaching in SWC structures that occurred due to the force of runoff water from upper slopes. The gaps implied that severe erosion had taken place. The failure of one SWC structure could result in subsequent erosion damage in other downhill fields, creating both the gullies and breaking of other structures or infrastructures.

The survey revealed that the most observed soil erosion indicators were broken SWC structures, rills, stoniness, loose soils, sheetwash, root exposure and red soil. The other indicators were either less obvious to be seen and therefore rarely correlated to erosion damage or not commonly observed in the study area.

Farmers observed that most of the erosion indicators developed after combined influence of some determining factors: rainfall, runoff, steep slopes and soil surface conditions (soil structure, cohesiveness). Rainfall, runoff and steep slopes influenced development of rills, sheetwash, gullies, splash pedestals and partly the loose soils. Also farmers perceived that sheetwash influenced changes in topsoil colour and depth that resulted in red soils and root exposure. To a greater extent they perceived that shallow soil depth and impact of runoff were responsible for appearance of soil stoniness, gullies and broken SWC structures among others. Other authors have reported on farmer's knowledge of erosion processes that are in agreement with our findings. Nepalese farmers observed formation of splash pedestals and runoff development underneath the tree canopies, which they attributed to wide tree canopies (Joshi and Sinclair, 1998). Though Zulu community did not recognise splash erosion phenomenon but rills and gullies were clear features on their farms (Van Dissel and De Graaff, 1999). Rwanda farmers used soil surface characteristics that developed as a result of soil erosion to identify different productivity zones and types of soils (Steiner, 1998).

Table 1. List of erosion indicators identified in the farmers' fields (local names in parenthesis) and perceived causes for their development.

Erosion indicators	Observed indicators (%)	Perceived causes
Rills (*Tumivuko*)	93	Rainfall, runoff, steep slopes
Sheetwash (*Muguo*)	55	Rainfall, loose soils, steep slopes
Sedimentation (*Gukunikuo*)	26	Rainfall, runoff, steep slopes
Red soils (*Ithetu itune*)	43	Top soil removal, steep slopes
Root exposure (*Kuicirurio tumiri* or *miri*)	55	Sheetwash, steep slopes, loose soils
Stoniness (*Tumathiga*)	93	Runoff, shallow soil-depth
Rock exposure (*Mathiga*)	16	Runoff, shallow soil-depth
Gullies (*Mivuko minene*)	30	Rainfall, steep slopes, compound/road/roof runoff
Splash pedestals (*Matata*)	23	Rainfall, loose soils, tall tress
Loose soils (*Muthetu muvuthu*)	89	Raindrops, sheetwash, use of inorganic fertilizers
Broken SWC structures (*Kuomomoka kwa mitaro*)	97	compound/road/roof runoff, steep slopes, widely spaced structures

Classification of erosion indicators

To gain insight in the farmers' knowledge of erosion indicators, we asked the key informants to reclassify the listed indicators with regard to the duration taken before they were clearly detected. The indicators were classified into current and past erosion indicators (Table 2). According to farmers, past erosion indicators were observed after several cycles of erosion events that lasted at least three months (one rainy season) or several years of rainfall events. Current erosion indicators could be observed after a single or up to three rainfall events. Farmers observed that current erosion indicators could easily evolve into past erosion indicators if erosion control measures were not applied.

These findings suggest that farmers are aware of both the short (current indicators) and longterm (past indicators) impact of soil erosion on their land. But despite the knowledge and evidence of these indicators, farmers were less worried by the formation of the current erosion indicators. They perceived them as reversible because they would be obliterated seasonal through ploughing and weeding. Because of that they hardly related these indicators to the decreasing crop yields and therefore not given priority among their production problems (Wenner, 1989). Besides, sedimentation would hardly be observed as a problem to most farmers as it represented an area of high soil fertility. Lal and Elliot (1994) observed that current indicators were easy to permanently reverse by change of landuse and land management practices that improved soil structural stability and organic matter content. Farmers who did not take permanent remedial action on current erosion indicators, more permanent, spatially distinct and irreversible forms of erosion indicators tended to develop and remain exposed on the soil surface. Splash pedestals are clear indicators of high sheet erosion rates of orders of 50 t ha^{-1} per year or more (Stocking and Murnaghan, 2001). Several years of temporal "removal" of the less recognised pedestals could however lead to drastic lowering of the soil's productive capacity, resulting in reduced yields or need for higher inputs which poor farmers can ill afford. Most likely course of action by the poor small-scale farmers would be to identify alternative crops to grow or economic activities on the newly developed soil surface characteristics. For instance, it was observed that majority of farmers in the study area chose to plant *mirraa* crop in areas dominated by past erosion indicators since annuals could hardly grow there. Some farmers were also observed to engage in stone crashing to make construction ballast for cash income generation. Similar attitudes were observed with Canadian Prairie farmers, who perceived areas with past erosion indicators as unworthy the effort to restore for crop production (Kirkwood and Dumanski, 1997).

Table 2. Farmers' classification of current and past erosion indicators

Current erosion indicators (reversible)	Past erosion indicators (non-reversible)
Rills	Rock exposure
Splash pedestals	Root exposure (in trees)
Sedimentation	Stoniness
Sheetwash	Red soils
Root exposure (in food crops)	Gullies
Broken SWC structures	Loose soils

Spatial distribution of erosion indicators

Distribution of erosion indicators is not only affected by duration of erosion processes and land management practices but also by the distance from the hydrological divide (Bergsma and Farshad, 2003). Our attempt was to assess the spatial distribution of the identified indicators in the cultivated fields over the different slope gradients. The individual fields in the study area tend to run in a downslope direction. The very top of the hillcrest has the flat (<6%) and gentle slopes (6-15%) followed by the steep slopes (15-32%) at the mid of the hillslope and then the very steep slopes (>32%) before encountering the valley bottom areas. Most of the farmers we interviewed had their fields covering all the slope classes. The survey showed that six of the eleven indicators (shown in Table 1) were observed by the majority of farmers on different slope positions (Fig. 1). The rest of the indicators were less frequently observed with respect to slope positions and hence not discussed here. In general, of the 120 farmers interviewed, rills were observed by 93% of farmers, root exposure by 55%, sheetwash by 55%, red soils by 43%, gullies by 30% and sedimentation by 26% of farmers (Table 1). All the erosion indicators the interviewed farmer observed were noted and the general slope gradient, for that location in the field, was measured using a slope inclinometer.

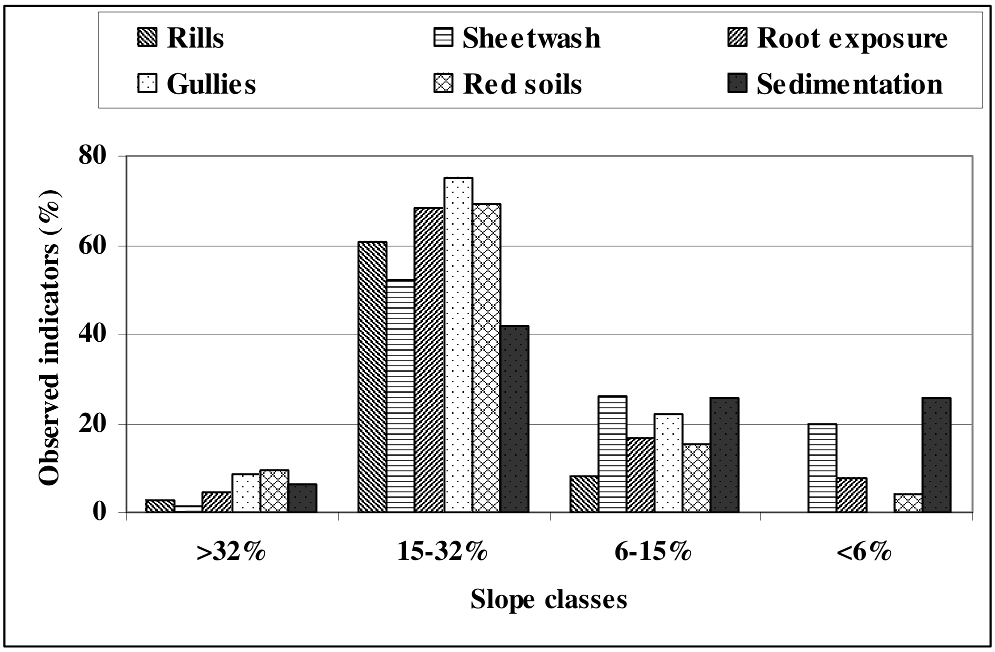

Figure1. Identification of typical erosion indicators on different slope positions found on all farms in Gikuuri catchment. Most of the farms characteristically run from the ridge-top (flat, <6%) through very steep slopes (>32%) to the valley bottom.

Results indicated that all the six indicators were observed to develop on all the slope positions except the gullies and rills, which were not observed by farmers on flat slopes. There was however a steady increase in percentage of farmers who observed all the six indicators with increasing slope steepness, except at the very steep slope position. This is possibly because the fields in the very steep slopes have undergone longterm erosion processes therefore very little erodeable soil material is left except for hardpans and bare rock surfaces. It could also be that very steep slopes had very effective conservation measures.

This study does imply that because there was remarkable presence of current and past erosion indicators, erosion processes are still active and have been ongoing for some time in the area. The indicator distribution on slope positions does indicate the strong influence of velocity of overland flow and slope steepness-length factors on the evolution of different types of soil erosion features (Morgan, 1996). In support of farmers' observations, Mutchler and Greer (1980) and Poesen (1984) observed a tendency of rills forming as slopes became steeper mainly as a result of concentrated overland flow that increased depth and number of rills on steeper slopes than less steep slopes. While Mati (1989) attributed severe rill formation on conserved fields to improperly laid out SWC structures. This would probably explain why erosion indicators were widely observed in all hillslope positions despite the widescale adoption of SWC in the study area. Farmers prefer to space conservation measures widely, against technical recommendation, because they perceive that conservation measures unnecessarily take out much of the land that would otherwise be available for crop production.

Estimation of erosion damage

According to our discussions with the key informants, they perceived that there was an association between erosion indicators and perceived soil loss levels. But they stated that they were unable to estimate actual soil loss from their fields other than relating certain on-site erosion effects (erosion indicators) to different soil loss rates (Table 3).

Table 3. Farmers' qualitative estimation of soil loss rates using soil erosion indicators.

High erosion rate	Moderate erosion rate	Low erosion rate
Rills	Root exposure (trees)	Loose soils
Sedimentation	Sheetwash	Root exposures (food crops)
Gullies	Red soils	Splash pedestals
Broken SWC structures	Rock exposure	
Stoniness		

Other findings on farmers' perception also illustrate the common practice of farmers relating erosion indicators to soil degradation by erosion. The association of certain indicators to a particular level of soil loss rate can in some cases dependent on soil conditions, type and rainfall amounts. A survey by Kirkwood and Dumanski (1997) on expert farmers of Prairie province, Canada, associated small rills to slight (low) erosion while larger rills and small gullies, sedimentation and stoniness were an indication of moderate erosion. Only gullies, among our list of indicators, were associated to severe (high) erosion. Despite failing to recognise the phenomenon of splash erosion, rills and gullies were associated to high erosion rate by small scale farmers of South Africa according to Van Dissel and De Graaff (1999).

Differences between scientific evidence and farmers' perception are clearly obvious on how the effects of sheet erosion on soil and crop yields are perceived. While scientists have evidence that sheet erosion (sheetwash) has the most severe damage on soil productivity (Rickson et al., 1993), our farmers and other studies on farmers' perceptions of soil erosion perceived otherwise (Östberg, 1995; Kirkwood and Dumanski, 1997). This is probably because of lack of dramatic evidence of decreased crop yields and masking effect of deep top-soil depth layer during the early stages of soil erosion process.

We wished to establish from farmers how they rated each of the indicators, in terms of relative importance to soil damage. The key informants' computed weights using the pairwise comparison method. Relative importance for each indicator, expressed as a weight index, was calculated. Past erosion indicators, namely gullies, broken SWC structures, rock exposures and stoniness indicated more severe erosion damage than the current indicators (Table 4). The higher the indicators' weight the more severe was its effect on soil biophysical characteristic and thus overall soil productivity damage. The key informants perceived that use of the relative weight index was much simpler and useful when quantifying the compounded effects of multiple indicators on a given site. This was illustrated by using four eroded fields identified in the catchment (Table 5). The results show that though field C had only two predominant indicators, its overall weight value was higher than field A, with three erosion indicators. The illustration also showed that it was not enough to compare the erosion damage or risk solely on basis of the number of erosion indicators but more important was to consider their individual weights, which may markedly vary (see fields B versus D and C versus D).

Table 4. Relative erosion indicator weights for predicting soil erosion damage

Erosion indicators	Relative weight ratio
Gullies	0.17
Broken SWC structures	0.15
Stoniness	0.14
Red soil	0.12
Rock exposure	0.11
Rills	0.09
Root exposure	0.08
Sedimentation	0.06
Sheetwash	0.05
Splash pedestals	0.03
Loose soil	0.02

Table 5. Example of using relative erosion indicator weights to express the effect of soil erosion

Cases	Indicators observed	Severity of soil damage+
Field A	Sheetwash, root exposure, splash pedestals	∑weight(0.05+0.08+0.03)=0.16
Field B	Rills, root exposure, red soils, loose soils	∑weight(0.09+0.08+0.12+0.02)=0.32
Field C	Rock exposure, stoniness	∑weight(0.11+0.14)=0.25
Field D	Gullies, broken SWC	∑weight(0.17+0.140=0.32

+Severity of damage was assessed by summing up individual indicator weight in Table 4

This valuation system could be relevant for quick estimation of the extent of soil erosion damage both by the scientist and farmers without requiring traditional erosion assessment experiments. Supporting use of farmers' knowledge of surface soil degradation indicators, Habarurema and Steiner (1997), and Stocking and Murnaghan (2001) observed that farmers were richly endowed with knowledge that they used to systematically judge parts of the field. Oberthür *et al*. (2004) observed that farmers were able to change management strategies on one part of the landscape on basis of the differential distribution of fertility indicators.

Therefore based on the illustrated use of indicator weights (Table 5) we could state with certainty that severity of damage is dependent both on the multiple intensity of erosion indicators and on total weight of indicators. Though a great deal of work has been carried out with appreciable attempt to estimate soil degradation in the perceived high, moderate and low erosion sites (Frye *et al*., 1982; Schertz et al., 1989; Kirkwood and Dumanski, 1997; Bergsma and Farshard, 2003), no attempt has been made to identify the specific erosion indicators in those sites. With the knowledge of the indicators at the degraded areas, it could be more rational to associate or attach to these indicators certain range of productivity losses. This would enhance knowledge of farmers and field technicians in determining the inputs and/or the urgency to apply control measures. As such, given the scarcity of this kind of information in literature we are currently trying to assess soil loss and yield gap equivalence on sites with prevalence of current and past erosion indicators in the East African highlands.

Conclusions

Farmers in central highlands of Kenya cannot be assumed to be ignorant of the much reported widespread soil degradation phenomenon. They are knowledgeable of the water erosion processes and the consequent on-site erosion impacts. They have clear understanding of various forms of erosion indicators spread over the landscape and which adversely affect their soils. Gaps or breakage in SWC structures, rills and stoniness are examples of evidence that existing erosion control measures are not effectively preventing soil erosion. The indicators were noted to intensify in type and number with increase in slope steepness towards the valley bottom areas. This is likely to become rampant given the cultivated steep sloping landscape that characterises the high rainfall highlands of Kenya. As a result, some hillslope positions are becoming of less importance for crop production due to past soil degradation. Use of farmers' knowledge has demonstrated that though current indicators could be arrested they are left to develop into past erosion indicators. Farmers can actually distinguish between different eroding areas using their knowledge of the indicators associated to different soil loss rates. Quantification index can be useful in identifying areas that require either extra soil-nutrient or conservation attention. By this approach it might be much easier to convince farmers to only target areas that are more severely damaged rather than enforcing conservation of the whole field or landscape, for reasons that may not be clearly understood by them.

Therefore, a more participatory approach is needed to employ the farmers' knowledge of erosion indicators for identifying degraded areas, and semi-quantify soil damage. The use of indicator identification, mapping and computing the equivalent soil damage approach could significantly facilitate extension agents in assisting farmers in targeting specific areas that require conservation attention.

Acknowledgements

This research was conducted as part of the ISNAR funding to The Methodological Development of an Improved Method for SWC Planning at a Catchment scale in the East African Highlands project from 2000 to 2004. We therefore wish to express our appreciation to ISNAR office (The Hague in the Netherlands) for the timely release of funds and KARI for facilitating its use during the project period. We wish to thank the key informants, the chiefs and location and village leaders from Runyenjes Division who supported us during the surveys. We highly appreciate the views and rich knowledge availed to us by the farmers who were interviewed and those who attended our general meetings. Leonard Musiega (project field technician), KARI and Ministry of Agriculture staffs are highly acknowledged for their input during the survey.

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Chapter 4

QUANTIFICATION OF SOIL EROSION INDICATORS IN GIKUURI CATCHMENT IN THE CENTRAL HIGHLANDS OF KENYA

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Submitted to: GEODERMA (2004)

Quantification of soil erosion indicators in Gikuuri catchment in the central Highlands of Kenya

Abstract

Quantification of soil erosion using conventional approaches is hampered by lack of extensive spatial coverage and long duration data. Instead scientists have resorted to using conventional approaches resulting to unsatisfactory landuse plans that are in great disparity to on-site observations by farmers. Farmers have great knowledge of what they perceive as the indicators of soil erosion, which have so far not been empirically linked to actual soil loss or crop yield rates. This study was conducted to attach quantitative values of soil loss and maize crop yields to on-site erosion and sedimentation indicators as perceived by the farmers in the central highlands of Kenya. Soils exhibiting splash pedestals, sheetwash, rills, sedimentation, red soils and stoniness were among the many erosion indicators selected for quantification. Three soils types and three slope gradients were identified and on each runoff plots were installed to relate the sheet-rill erosion developments to actual soil loss. Whereas the temporal changes of the rills and pedestal height (sheet erosion) were used to quantify erosion rates within nine bounded runoff plots, five erosion indicators were identified within 24-31 farmers' fields with an aim of estimating crop yield gaps. Statistical procedures applied included correlation matrix, linear regressions and analysis of variance using Duncan' multiple range tests within the SPSS program. The study observed that the temporal and spatial dynamics of topsoil levels and various dimensions of the rills were influenced by slope length and continuity in rain days. Whereas soil loss significantly correlated with all rill dimensions the topsoil depth least influenced it. Topsoil profile depth, rill depth, width and total length were found to be significant variables that accurately described the actual soil loss in a field condition under sheet and rill erosion phenomenon. Two model equations were constructed relating soil loss rates and both the rill sizes and decline in topsoil depth. But also and five widespread erosion indicators were empirically linked to specific crop yield levels. Because of soil erosion a crop yield gap of over 50 percent was observed in fields bearing superficial stoniness and sedimentation indicators. On basis of these results rate of soil loss can now be estimated at field scale by fieldworkers in situations where sheet-rill erosion is prone within a rainfall event or season. This would assist in satisfactory and timely advice to the farmers on aspects of soil and water conservation instead of relying on ill-fitting conventional erosion models. Besides knowing soil loss rates, crop yield decline experienced by farmers could be useful data for forecasting the potential soil erosion status or conversely use observable soil surface erosion indicators to determine the crop yield ranges the farmers were likely to harvest.

Keywords: *Farmers' knowledge; Soil erosion indicators; Soil erosion rates; Crop yield gap; Kenya*.

Introduction

Traditionally, soil losses by water erosion have been estimated using runoff plot measurements and a wide range of erosion models. The runoff plot experiments are not only resource demanding to undertake but also are site-specific and only quantify factors that are responsible for erosion processes (Mutchler *et al*., 1994; Morgan, 1996; Stroosnijder, 2003). Furthermore, by nature of the scale of the plot sizes, the measurements are only limited to the description of the basic erosion phases, such as raindrop detachment, splash transport, interill erosion and rill formation (Mutchler *et al*., 1994). That is why the attempts to extrapolate soil loss data from such plot sizes can result in unsatisfactory results mainly because of the temporal and spatial variances of the soil erosion factors (Shrestha *et al*., 2004). Alternatively, use of models for assessment of soil erosion has been preferred on justification that runoff plot measurements do not cover major soils and land-use types (UNEP, 1997). But yet validation and calibration of these models are performed using data from runoff plots on different land-uses, soils and topographic conditions. Whether empirical or process-based models, they can only be useful tools for planning if they are based on good field measurements that were acquired from extensive spatial coverage and during long duration. Since these conditions are rarely met, most model outputs are derived from input data generated by estimates and pedotransfer functions (Pla, 2003; Stroosnijder, 2003). Because of lack of appropriate approaches to evaluate soil degradation, the land-use planners in most countries have adopted recommendations that are derived from site-specific experiments or based on modelling approaches that are not fitted to the local conditions. Lal (1994) observed that land use planning decisions based on unreliable data could lead to costly and gross errors. Consequently, current estimates of soil erosion rates have been subjective and have not enabled extension agents (or policy planners) to correctly estimate soil loss and to accurately design cost-effective soil conservation plans in agricultural lands (Kilewe, 1986; Napier, 1989). Neither use of simulated data (De Ploey, 1983; Kilewe and Mbuvi, 1990; Biot and Lu, 1995) nor analysis of eroded materials (Lal, 1976; Gachene, 1986; Gachene *et al*., 1997) has enabled on-site soil erosion assessment to improve crop production. According to Tengberg *et al.* (1997) and Stocking (1988), these techniques inhabit potential errors, e.g. on crop yields and preferential removal of both the soil nutrients and sediment materials, which could not pertain if erosion were induced by natural rainfall.

Therefore increasingly there are calls for integrating scientific and farmers' knowledge of the current soil degradation and options for improving soil management (Barrios *et al*., 2000; Gobbin *et al*., 2000; Pla, 2003). What is required, and yet lacking, are the low-cost and appropriate approaches for quantifying effects of soil erosion on soil productivity. These approaches need to be accurate and replicable in similar conditions in the cultivated agricultural lands. The evidence of soil erosion processes can be useful in mapping its widescale effect on soil productivity. Soil erosion indicators develop on soil surface in varying temporal and spatial forms. Studies have reported widescale knowledge of land users in employing these indicators for estimating the extent and effect of soil erosion on soil productivity potential (Okoba and Sterk, 2004). The erosion indicators not only reflect the changes in the soil properties but also determine the current status of severity of soil erosion and crop production potential (Gameda and Dumaski, 2004). Though crop production is a function of many factors including climate, management and slope it is strongly influenced by inherent soil properties (Tengberg and Stocking, 1997). Some of the most common physical erosion-induced degradation indicators that affect soil productivity include natural stripping-off of topsoil by sheetwash, rill incision, quantity and quality of sediment deposits in the valley bottom areas and the exposure of sub-soil layers. These are perceived vital indicators since they not only undermine soil productive potential but also make agricultural production extremely risky and costly.

As a result of inaccuracies in the conventional approaches, use of a combination of farmers' indigenous knowledge and scientifically proven measurements on the widespread *in-situ* soil degradation indicators has been widely suggested (Mannaerts and Saavedra, 2003; Roose, 2003; Pla, 2003). Use of such indicators could provide more reliable evaluations of erosion status than conventional approaches, which are largely limited by relief and climatic differences. According to Rhoton *et a*l. (1991), the effects of soil losses are better understood when on-site soil conditions are evaluated, since the exposure of soil surface horizons gives more insight on the current and past erosion impact. Moreover it was the yield levels on these soil conditions that farmers were more interested in than the quantities of eroded soils or change of soil properties (Stocking, 1988). But though the farmers have a perceived linkage between the erosion indicators and crop yields, the actual yields have not been established. This study aimed to attach quantitative values of soil loss and crop yield to on-site erosion and sedimentation indicators as perceived by the farmers in the central highlands of Kenya.

Materials and Methods

The study used consensus knowledge of farmers of the widely evidenced soil erosion indicators on the cultivated lands from the East African highlands. The site was located at Gikuuri catchment (00^o 26´S, 37^o 33´E at an elevation of 1302-1500 m) in Runyenjes Division of Embu District in Kenya. The annual rainfall is about 1270 mm and is distributed in two seasons; the long rains are experienced from March to May while the short rains are from October to December. The smallholder farming practices are commonly mixed crop-livestock systems. Intercropping of coffee with food crops (beans and maize) has become common practice given the low market prices of coffee. Agroforestry in the area mainly comprises of *Gravillea robusta* trees for poles and fuelwood, and fruit trees intercropped with food and cash crops. Farmers however avoid deliberate inclusion of trees in cropland due to shading and, soil-nutrient and moisture competition caused by trees on their food crops. Most common niches for *Gravillea* trees are along the field and homestead boundaries and as woodlots in the valley bottom areas. Dairy cattle are kept but on zero-grazing system because of the small landholdings.

The soils are developed from volcanic rocks. There are six soil types but only four are used predominantly for rain-fed agriculture. The four soil types include rhodic Nitisols, haplic Acrisols, chromic Luvisols and chromic Luvisols/Cambisols. The two soil types (dystric Gleysols and Fluvisols) cover narrow strips in valley bottom areas and are mostly used for irrigated agriculture and not considered in this paper. The upstream soils are generally well-drained, very deep with dark red aggregated clays where erosion has not taken place otherwise deep red with a thin A-horizons. The topsoil and subsoil contain a high percentage of clay (over 70%) (Wanjogu, 2001). The topography is highly dissected with gently undulating to hilly landscapes. The hillslopes exhibit a complex profile that runs in a longitudinal gradient starting from the flat ridge summits (short, 10-20 m) to convex slope forms (long, 100-120 m) and concave slope forms (long, 50-180 m) in the midslope areas and ending in the valley bottom areas. Due to a high population density the cultivation on steep concave-convex hillslopes is carried out indiscriminately with inadequate soil conservation measures thus enhancing soil erosion.

Table 1. Description and classification by farmers of the soil erosion indicators widely found in the central highlands of Kenya

Erosion indicator	Brief description	Class‡
Splash pedestals	Describes the created craters by raindrop and protected soil column by stone, root or crop residues. Found under and outside tree canopies.	C
Sheetwash	Marked by runoff flow path leaving smoothened surface that shows direction of the flow.	C
Rills	Are continuous or discontinuous channel. Observed to develop after an intensive rainfall event, commencing from a short distance from ridge-crest or base of maize stem; due to the leaf structure that concentrates canopy-intercepted rainfall.	C
Root exposure	Exposure of aerial roots after topsoil is stripped off by runoff and splash effect of raindrop. Indicates that topsoil had been removed thus weakening the crop stability.	C/P
Sedimentation	Identified by the burying of crops/grass or deposition of "new soil". Marked by fertile or infertile zone in a field. Soil material could be dark nutrient-rich or coarse sandy/stony deposit.	C
Broken SWC struct.	Marked by gaps in formally continuous strips/bunds of conservation structure. Sign that runoff was too much to be contained by the existing structures.	C
Stoniness	Small loose stones lying on soil surface. Signifies that overlaying topsoil and subsoil layers have been removed by water erosion.	P
Rock outcrops	Partly exposed rocks. Indicates that soils are shallow and have been washed off by runoff flow, exposing tips of underlying parent rock.	P
Gullies	Larger than rills and locally distinguished from rills when a 7 year-old child cannot jump across.	P
Red soils	Implies that top-dark soils have been removed by runoff, also used as a strong indicator of severely eroded - leaving unproductive soils.	P
Loose soils	Implies soils that are prone to wind erosion and easily scoured by runoff water. They are neither dark nor red but have poor water holding capacity. Do not occupy large areas since they are interspersed between red and darker soils.	P

‡C = current erosion indicators; P = past erosion indicators.

The commonly found soil erosion indicators in the study area, which were also classified as current or past erosion indicators (Okoba and Sterk, 2004) are listed in Table 1. The farmers defined current erosion indicators as those indicators that developed within a single or couple of rainfall events but whose evidences were easily obliterated during tillage operations, thus also referred to as reversible indicators. Whereas the past erosion indicators were those erosion indicators that have developed progressively to more severe erosion conditions mainly due to negligence of the recurring current indicators. They cannot be obliterated through tillage operations or restorative management in a short-term period (irreversible indicators).

Though various indicators can be evidenced on the soil surface, accounting for their individual influence to soil loss or crop yield can be difficult, especially in a field-based experiment. Given the difficulties of isolating the different erosion indicators for purpose of attaching the equivalent soil loss or crop yield, sites exhibiting current and past erosion indicators were identified. The researchers and the farmers by consensus made the following groupings to enable quantification of the various erosion indicators (Table 2). In order to quantify the current erosion indicators in terms of soil loss, bounded runoff plots measuring 2.5 m wide by 10 m long (Table 2, group 1) were installed within areas where the current erosion indicators were observed to occur in the farmers' field. The sites and size of the plot were determined after several transect surveys across the study area during the rainfall season prior to the onset of this research. The transect surveys entailed observing, measuring and recording the network of rills along the hillslopes. The widest and the longest rill network dimension was taken to represent the system of rill and sheet erosion that is observed on cultivated hillslopes before eroded materials are deposited in the valley bottom or against an erosion control barrier. Three of the six soil types were selected, because of their widespread coverage, and within each soil type three slope gradients were identified for installation of the runoff plots. The three widespread soils were the rhodic Nitisols, chromic Cambisols and haplic Acrisols. The runoff plots in each soil type were installed on slope gradients classified as: gentle (6-15%), steep (16-32%) and very steep (>32%). In total nine runoff plots were set up to relate sheet and rill erosion development to quantities of soil loss during four rainfall seasons in the years 2002-2003.

Table 2. Soil erosion indicator groupings for quantification at plot and field scales

Group	Indicator type	Assessment scale *
1	Splash pedestals (also for sheetwash-root exposure) and rills	Plot and field
2	Sedimentation	Field
3	Red-loose soils	Field
4	Stoniness	Field
5	Control†	Field
6	Broken SWC structures, rock-outcrops, gullies	none‡

† Stands for soils where farmers perceived to have had no erosion, sited at the ridge-tops/hillcrest and protected areas within home compounds; * Plot size = 2.5 m by 10 m and Field net plot sample size = 3 m by 3 m; ‡implies that these indicators were not evaluated.

Runoff plots were bounded on three sides with a galvanised metal sheet buried 25 cm in the ground and 25 cm left projected above the ground surface. At the bottom end of the plot, a trough box (2.5 m long by 0.45 m wide by 0.45 m high) with a hinged lid received all the surface runoff before conveying into the storage tank by a 10cm diameter drainpipe. During an erosive event eroded soils (mud or sludge) were deposited in the trough box whereas the sediment in runoff suspension was collected into a storage tank (200 litres). The total sludge from the trough box was weighed and a representative sample collected and later oven-dried to determine its water content and consequently the equivalent mass of dry soil in the trough. Similarly total runoff (in the storage tank) was measured using a calibrated dipstick (for large runoff volumes) after thorough mixing of the runoff in the storage tank. The depth of runoff was converted into its volume using an equation that was dynamically derived at the onset of the experiment. Two representative sediment samples (in a pair of 0.5 litre bottles) were then taken for determination of sediment concentration in the runoff suspension in the tank. Total soil loss was calculated by adding up the equivalent mass of dry soil in the trough box and in the storage tank. All samples were oven-dried at 105°C overnight for determining mass of dry soil. After every erosive storm, the trough box and sludge tank were cleaned and set for the next erosive rainfall event.

In each of the runoff plots maize was grown as a test crop. Tillage operations were carried out twice in every rainfall season, using hand tools (hoe and machete) for weeding and digging up the soil. The crop and tillage practices were similar to the farmers' practices in the area. Details on the monitoring of sheet erosion using pedestal gauges and rill incision by measuring rill channel dimensions are described here below.

Monitoring of surface erosion features

According to Lal and Elliot (1994) and Stocking and Murnaghan (2001) splash pedestals represent an un-eroded soil column on the soil surface protected by a cap of resistant material (stone or root). A pedestal is an evidence of the effect of raindrops on the soil surface and the removal of topsoil layers by action of the sheetwash. In this study artificial pedestal gauges were installed in the runoff plots (Fig. 1) to monitor topsoil decline due to combined effects of raindrop splash and sheetwash erosion processes, which by extension also influenced progressive root exposure of cereals and legume crops. These gauges were made from thin plastic strips, about 2 cm wide by 10 cm long and fastened onto the soil surface using bicycle spokes. The spokes were pushed into the soil through the holes (on the edges of the plastic strip) until the strip was flush with the soil surface. The strip was placed on the soil surface with its length in a downslope direction. This was to avoid undermining of the soil pedestal by overland flow. The pedestal gauges were placed after the initial rainfall events during the rainfall season; to ensure that soil aggregates were well compacted and stable by the initial non-erosive rainfall events. Changes in soil surface height were measured using a slide vernier calliper, precise to 0.01mm, during every measuring campaign. The new soil surface around the pedestal gauge was noticed by a formation of soil pedestal column or soil sediment covering the plastic strip. Two gauges were placed at every one-metre interval starting at 2m-distance from the upper edge of the plot in downslope direction (Fig. 1). As a complementary measurement to account for contribution of sheetwash and raindrop splash, erosion pins were also installed in the same runoff plot as the pedestal gauges. Erosion pins, 30 cm long, made of bicycle spokes were pushed in the soil until half the height, at 15 cm reference mark, was flush with the surrounding ground level. The effect of sheet erosion was measured from the top of the erosion pin to the new soil surface using a slide vernier calliper. The changes on the soil surface were calculated by subtracting the initial height of the pin or pedestal gauge from the new height. Positive change meant sedimentation while a negative change was indicative of erosion.

Rill sizes (depth, width and length) were monitored by transect surveys both in the across the slope and along the plot in the downhill direction following the Assessment of Current Erosion Damage (ACED) methodology (Herweg, 1996). Survey grids of 0.5 m (across) by 1.0 m (downslope) were marked on the metal sheets along the boundary of the runoff plots to guide and ensure that repeated recording and measuring of rills is maintained within the same grid area (Fig. 1). The rill depth, width, number of rills and rill length were assessed within each grid cell in the entire plot. The depth and width were measured using a slide vernier calliper while rill length was measured using a tape meter. Both the total rill length and total number or count of rills observed in each grid cell were recorded and summed up for the whole plot. Similarly, the volume of rills, rill width and depth in each grid cell were averaged for the whole plot area.

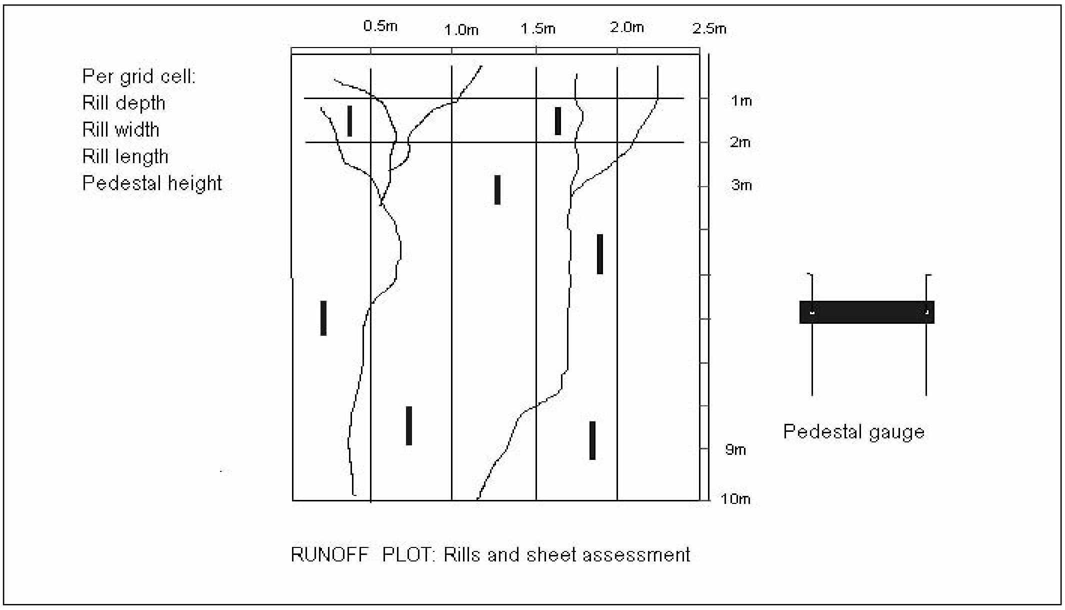


Figure 1. Schematic diagram of erosion plots showing splash pedestal gauges and dimensions of the grid cells within which changes in rills and topsoil profile (sheet erosion) were monitored.

Linking changes in surface erosion indicators to the corresponding soil loss

This step aimed to account for the eroded soil using changes in the average dimensions of the rills and topsoil profile depth. This was undertaken by measuring rills and topsoil profile in predetermined temporal and spatial intervals during the rainfall seasons. To ensure that changes on the soil surface due to erosion were accounted for, no disturbance to the topsoil was allowed before measuring and recording of the changes in rill depth, width and length, and changes in topsoil profile in the interill areas. The noted increases in rill and topsoil profile dimensions were associated to the soil loss collected in the previous rainfall events prior to the date of recording the measurements. On subsequent assessment of the changes in the erosion indicator variables, the new dimensions were associated to the cumulative soil loss since the beginning of the erosive rainfall events. This matching of variable dimensions was only discontinued and started anew in cases when soil surface was disturbed by tillage operations. The measuring of pedestal heights and dimensions of the incised rills was carried out only after experiencing continuous 2-3 days of no rainfall events. This was to ensure that the soil surface was not muddy and movements within the grid cells, to measure changes in rills and splash pedestals, would not affect the soil surface profile.

A second approach to quantify surface erosion indicators (both current and past erosion indicators, Table 1) was carried out through measurement of crop yields in fields where these soil erosion indicators were observed. The fields clearly exhibiting one or more erosion indicators shown in Table 2, were identified and selected across the study area. In the first two seasons of 2002, 12 fields representing control conditions of erosion indicator, 4 for splash-rills, 6-7 for red/loose soils and 5 for stoniness fields were selected. Soils representing sedimentation indicators were not monitored during this year. However, in 2003 the number of selected fields in first and the second cropping season differed. In the first rainfall season 14 fields represented control conditions of erosion, 4 had in splash and rills, 8 had red or loose soils, 4 had stoniness and 8 showed sedimentation features. In the second rainfall season 20 fields represented the control conditions, 4 had splash and rills, 16 had red or loose soils, 5 had stoniness and 6 showed sedimentation features. These indicators were found in different topographic positions on the landscape, except for sedimentation that was typical to valley bottom fields. The reason for selecting a number of fields in control conditions was to use them as a reference to determine the crop yield gap in soils with different erosion indicators. Within every selected field, a plot (3 m by 3 m) was marked. Organic and inorganic fertilizer inputs were applied in all fields to remove effect of past erosion impact on soil quality and standardize possible spatial differences between soils in the study area. Though maize was planted in the whole of the selected fields, only the maize harvested from the marked plot was considered for our analysis. The harvested maize was threshed and sun-dried and the final grain weight (in ton ha^{-1}) calculated after adjusting to 13 percent moisture content (standard moisture content for maize grains).

The analysis of the measured erosion indicator variables in runoff plots and comparison of grain yield in the farmers' fields were done using the SPSS program. Correlation coefficient analysis between different indicator variables related to soil loss was applied. Linear regression was used to identify relationships with acceptable coefficient of determination (at least over 50 percent) and variables that were of significant influence in the regression model equations. Crop yields from different soils exhibiting various erosion indicators were evaluated to determine the mean differences and relative percent crop yield gap, which is an index of soil erosion impact. Yield means were compared using Duncan' Multiple range test at 5% probability.

Results and Discussion

Relating physical surface erosion features to soil loss

During the study period rainfall amounts experienced varied within and between years (2002 and 2003). Rainfall during both seasons of 2002 was of higher intensities (max. 24 mm hr^{-1} for short rains and 44 mm hr^{-1} for long rains) and total amounts (more than 800mm in each season) than in 2003, which experienced lower rainfall intensities (max. 17 mm hr^{-1} for short rains and 24 mm hr^{-1} for long rains) and an average of 400 mm in each season. Long rainy days without a dry spell in between had significant effect on rill measurements, as dry days were necessary to measure rills within the runoff plots. Given the slippery nature of clays and steep slopes, instantaneous measurements were hampered after an erosive rainfall event(s) since movements within the plots would alter the topsoil erosion physiology. Therefore relating changes in rill dimensions and topsoil profile to the amount of eroded soils was a rather challenging task and yet of significant importance in this study.

Table 3 shows results of Pearson's correlation coefficient (r) among the measured variables in runoff plots during the study period. The results indicated that slope gradients and soil types did not linearly influence rate of soil loss. There were however significant correlations between soil loss and all the rill attributes. Also rill attributes correlated significantly among each other. These implied the high likelihood of observing linear influence of rill dimensions on soil loss rates. A remarkably high and significant correlation coefficient was obtained between rill volume and total rill length, implying higher contribution of rill length in calculation of rill volume than rill depth and width. Splash pedestal height, i.e. indicative of topsoil profile changes, though depicted insignificant and negative correlation with nearly all variables, it correlated positively to soil loss, Implying that there was a positive interaction between topsoil depth changes and soil loss. Moreover, because topsoil depth negatively correlated to rill attributes, which significantly correlated to soil loss, this could imply that most of the sediment in runoff was sourced from rill sidewalls and deepening in the bed layers.

Changes in size of rill channels and topsoil profile

Typical patterns that were observed during the monitoring of the topsoil profile and rill channels are illustrated in figures 2 and 3, respectively. Assessment of changes in topsoil profile level on one of the plots on three dates during the long rainfall seasons of 2003 are shown in Figure 2. It illustrates that during long rainfall season (Fig. 2A) detached material by raindrops was effectively washed off from the eroding sites by surface runoff, ensuring that no sedimentation phenomenon exceeded the original topsoil profile (the zero-line). This also suggested that detached materials were conveyed outside the plot through surface runoff flow and probably also through the rill channels. The situation was however different during the short rainfall season (Fig. 2B), where scoured profile was much shallower than in the long rainfall season, during the selected dates. Besides the first rainfall event having effectively removed all detached soil sediment, i.e. no sedimentation above zero-line, the subsequent rainfall events did not effectively evacuate the sediment from the eroding sites. This resulted in alteration of erosion and sedimentation spots along the slope length, especially evident at the 8-10th m distance. This phenomenon could be due to low intensity rainfall (7-17 mm hr^{-1}) in the season. Amount of soil loss (data not shown) during the short rainfall season was half of what was experienced during the long rainfall season despite the small difference in rainfall amounts. Low intensity rainfall resulted instead in higher infiltration rates than high runoff to transport all splash detached materials, leading to more sedimentation along the slope length. Govers and Poesen (1988) observed that only a minor amount of detached sediment during low intensity rainfall was finally evacuated from where they were transported by splash erosion into rill channels. They attributed this to size-selectivity of removed sediment leaving a coarser surface that could not be transported by sheetwash during low intensity rainfall and a compacted soil surface. These observations indicated that the short rainfall season characteristically resulted in lesser soil sediment evacuation from the eroding sites than the more intensive and erosive long rainfall seasons. The study also indicated that sheetwash caused a characteristic non-uniform removal of the topsoil material as depicted by sequences of erosion and sedimentation spots.

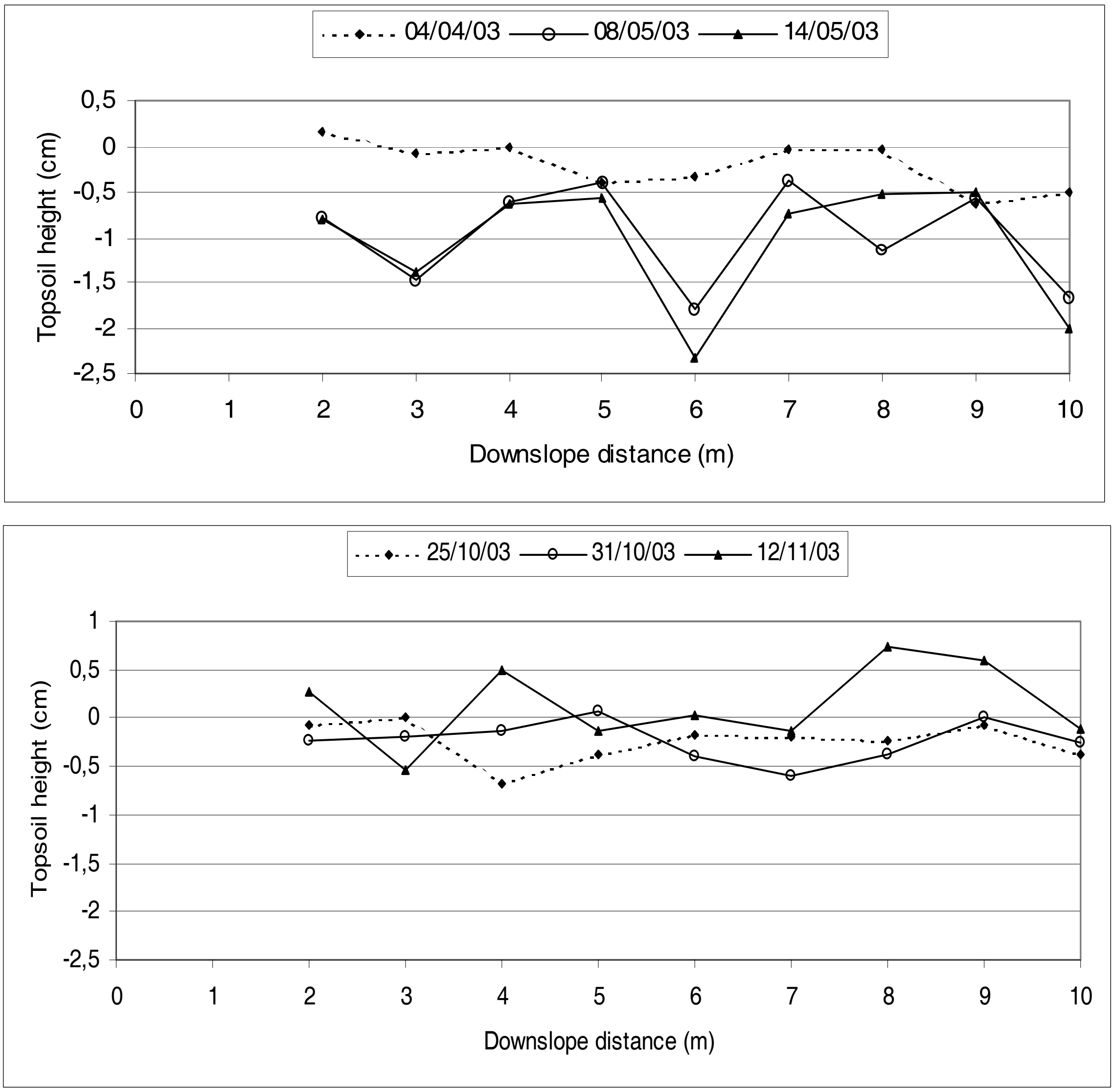


Figure 2. Changes in topsoil profile in time and distance in the downslope direction. Plot **A** represents specific days in the long rainfall season; showing more erosion than sedimentations relative to original topsoil surface (zero-line). Plot **B** represents specific days in the short rainfall season; showing more sedimentation (deposition) than effective soil loss relative to original topsoil surface.

Figure 3 (A, B, C) illustrates the dynamics of rill formation during the 2003 short rainfall season. In Figure 3A on 8/11/2003, rill incision was noted to have began at 3 m distance from the upper plot boundary and progressed incising up to the 9 m distance; failing to reach the end of the slope length. This trend was also observed with regard to the other rill attributes shown in Figures 3B and 3C. Rill depth remained much smaller than rill width across the slope length at every interval, indicating a rill width to rill depth ratio of about 3. This ratio did imply that the rill channels were of triangular or parabolic shapes, in agreement to field observations during the study. In a similar study, More and Burch (1986) found that hydraulically the most efficient rill shapes occurred when the rill width to depth ratio was more than 2. They suggested that the knowledge of rill dimension ratio associated to specific soil characteristics could be useful in estimating either the rill width or depth.

Table 3. Correlation matrix coefficients (r) on erosion indicator variables in three rainfall seasons (2002-2003) in Gikuuri catchment, Kenya

	Slope %	Soil type	Soil loss	Rill depth	Rill width	Splash pedestal height	Rill volume	Total rill length	Total nr. rills
Slope%	1	0.16	-0.15	-0.09	-0.27	-0.08	-0.10	-0.12	-0.12
Soil type		1	-0.35	**-0.53**	**-0.46**	-0.12	**-0.48**	**-0.53**	**-0.55**
Soil loss			1	**0.54**	**0.48**	0.23	**0.69**	**0.70**	**0.66**
Rill depth				1	**0.91**	-0.10	**0.71**	**0.75**	**0.75**
Rill width					1	-0.14	**0.56**	**0.61**	**0.63**
Splash pedestal ht.						1	-0.01	-0.03	-0.12
Rill volume							1	**0.95**	**0.85**
Total rill length								1	**0.95**

Note: Characters in bold indicate significant correlations at $P<0.05$

Table 4. Significant soil loss predictor model characteristics in Gikuuri catchment, Kenya

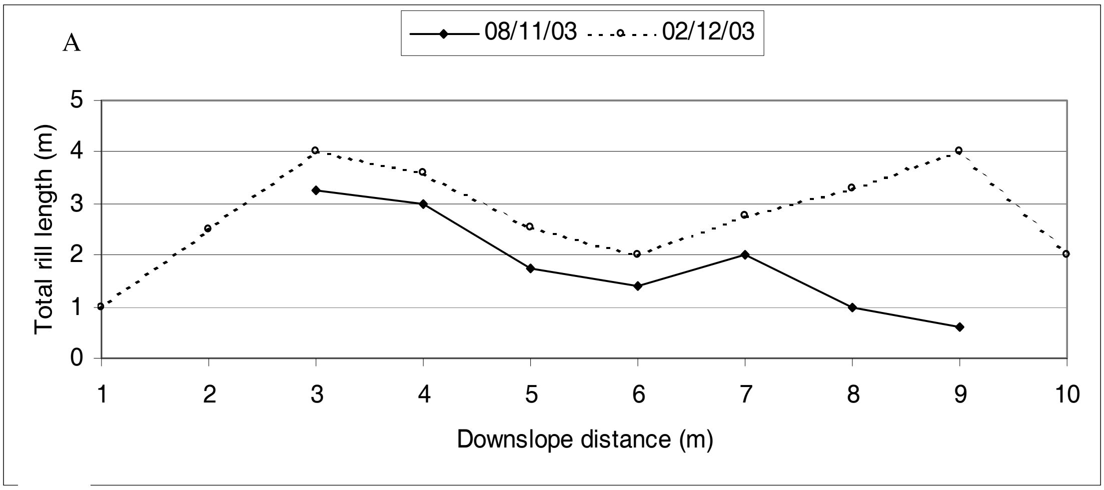
		Model accuracy	Variables' P- levels						
Regression equations‡	Equat.	R^2	R_D	R_W	S_M	R_L	R_DR_L	R_WR_L	R_V
$Y=0.128+0.0574R_D+0.440S_M+0.003R_L$	1	0.54	0.532		0.032	0.000			
$Y=-0.483+0.035R_W+0.462S_M+0.003R_L$	2	0.55		0.277	0.032	0.000			
$Y=1.149+0.437S_M+0.001R_DR_L$	3	0.56			0.026		0.000		
$Y=0.933+0.408S_M+0.001R_WR_L$	4	0.59			0.031			0.000	

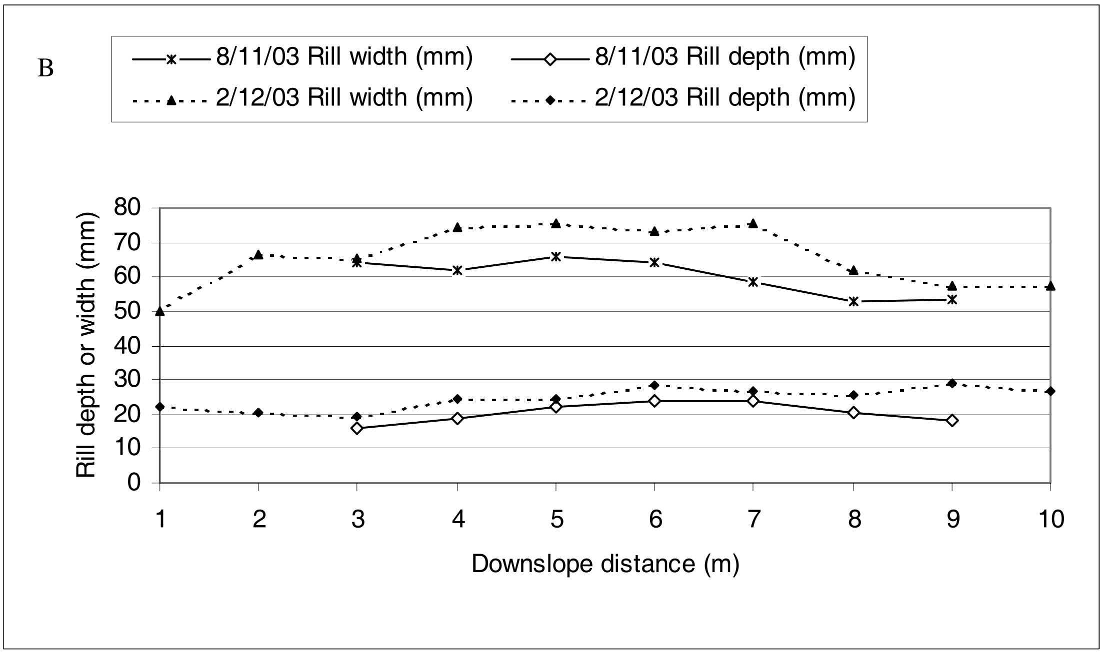
‡Where Y (ton ha^{-1}) is the cumulative soil loss; R_L (cm) is the total rill length; R_D (mm) is the rill depth; R_W (mm) is the rill width; S_M (mm) is the splash pedestal height; units for combined terms: R_DR_L or R_WR_L are in cm

During the second monitoring survey, on 2/12/2003, the rill dimensions had all increased and rill incision advanced both in forward and backward directions. But the retreat in the backward direction was limited to 1 m-distance from the upper plot boundary. This indicated that rill evolution, in time and distance, was greatly influenced by surface runoff volume, which increased with slope length. Consistent increase in rill depth and width (thus cross-sectional area) possibly responded to cumulative runoff volume and velocity along the slope ensuring the total evacuation of detached sediment in the runoff suspension. These findings are in agreement with others (McIsaac *et al*., 1996; Renard *et al*., 1997; Angima *et al*., 2003). Our study observed that during the rainfall season along the slope length there was progressive increase in total rill length and number of rills. Zone of no-erosion was within a distance of one metre (Figures 3 A, B, C). Rill incision further upslope was not possible probably because of lack of hydraulic conditions that influenced runoff generation (Morgan, 1996). Shrestha *et al*. (2004) observed lack of rill incision within 2-3m distance on slopes of 10-15% in the Nepalese Himalaya conditions, which emphasises the role of the slope length, steepness and infiltration characteristics of the soils.

Linking current erosion indicators to soil loss

In order to use the erosion indicators (rills and splash pedestals) to estimate the rate of soil loss from the eroding field, various rill dimensions and height of pedestals were regressed against the corresponding soil loss rates. Table 4 shows the regression equations and the variables found to account for the measured soil loss. Despite a relatively similar R^2 values in all the equations the significant levels (P-levels) of the model variables varied greatly. Firstly, the attempt to regress soil loss with a combination of rill depth (R_D), splash pedestal height or topsoil profile (S_M) and total rill length (R_L) showed that R_D was the only variable not significantly contributing to this model equation (P=0.53, Equation 1). Secondly, replacing R_D with rill width (R_W) in the regression, thus Equation 2, showed that R_W was similarly of insignificant influence (P=0.28) to the model. Combination of R_W and R_D could not be tried because of the illustrated strong correlation between them (refer to Table 3), which in effect would not give a reasonable linear regression equation. Because such an equation would result in showing negative coefficient values of either of the variables, which would imply a reduction in soil loss with unit increase in either of them. Attempt to transform these variables into natural logarithm did not however improve their influence to the regression equations. Consequently, interaction between rill length (R_L) and either R_D or R_W was considered, resulting to regression equations (Equations 3 and 4) having individual variables with significant influence to soil loss rate. The individual influence of S_M in all the equations showed more significant P-levels than R_D and R_W individually. The R_L was the strongest predictor variable of all the variables considered in the study. Its influence was depicted both by its individual significant levels ($P<0.001$) and its influence to overall soil loss when combined with other variables as an interaction term, such as R_DR_L or R_WR_L. Preferably, model equations 3 and 4 would be recommended for use by fieldworkers when determining soil loss, given the level of accuracy depicted (Table 4).





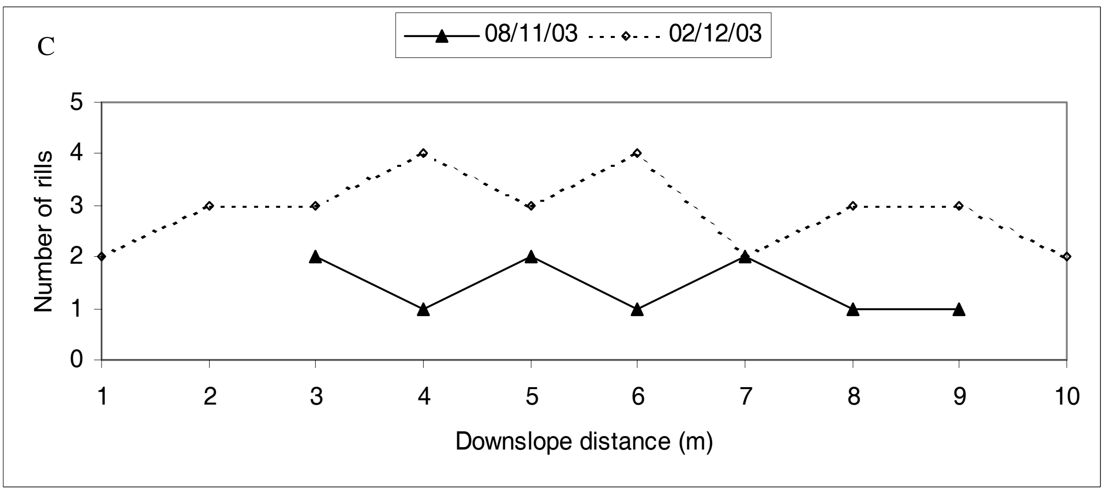


Figure 3. Changes in rill depth and width (A), total rill length (B) and number of rills (C) in time and distance in the downslope direction during short rainfall season in 2003.

Effective use of these models would depend on the variables the user can actually measure in a field undergoing soil erosion. Generally, the R_L variable is critical since it gives a reflection on the spatial extent of rill erosion (total length of rills) hence its importance in assessment of the actual total soil loss in the target area. These equations do not require the input of the area affected by erosion since they already consider the total length of rills in the entire area. Other authors found that rill erosion played a more important role to overall soil loss amount than sheetwash contribution (Collins and Dunne, 1986; Mtakwa *et al.,* 1987; Govers and Poesen, 1988; Herweg, 1996). Govers and Poesen (1988) stated that the importance of rill erosion to sediment yield was attributed to its progressive increase in supply of sediments to the runoff flow, unlike the sheet erosion that decreased because of the eminent sealing and compaction of the interill areas in time. This study found the high correlation between the soil loss rate and number of rills, rill length and volume, which can be explained by the reduced permeability in the interill areas and leading to strong rill incision, thus influencing soil loss rates. However, the two recommended model equations (3 and 4) accounted for about 56-59% of the soil loss, the rest of eroded soil could be accounted for by other influences that were not considered in this study.

Crop yields in relation to soil erosion indicators.

The effect of different soil erosion indicators on crop yield was measured in farmers' fields that have a widespread evidence of these indicators. Table 5 and Figure 4 show the series of crop yield levels during the experimental period. Generally, the absolute levels of maize yield and yield reduction varied between seasons (Table 5). Short rainfall (SR) seasons seemed to have higher yields than the long rainfall (LR) season in all the corresponding erosion indicator types. This observation could imply the influence of growth conditions in SR other than rainfall amounts. Given that all fields were equally supplied with organic and inorganic fertilizers, the yield differences were because of *insitu* soil physical properties represented by the erosion indicators. Within each season the mean maize grain yields did not significantly ($P<0.05$) differ between the erosion indicators except for the distinct differences between stoniness and control soils in all seasons but LR 2002. Stoniness soils reflected relatively the lowest maize yields across all the cropping seasons considering both the means and maximum yields. Next lowest productive soil erosion indicator was the sedimentation (in the 2003 seasons). Differences between maize grain yields in rill-sheet and red soils were very random and lacked clear statistical differences. Farmers perceived that soils prone to rill and sheet (splash-pedestals) indicators were more productive than where red soils were observed, but our results (Table 5, Fig. 4) showed otherwise. This can be attributed to efficient removal of nutrient-rich topsoil through the rill channels and surface runoff that enhanced decline in soil-water and plant nutrients storage reserves in topsoil profiles - required for crop development. Red soils tended to have coarse subsoil aggregates, which in effect reduced surface runoff to some extent though they were equally low in plant nutrients due to past loss of its dark topsoil profile.

However numerical differences among the soil erosion conditions showed a general crop yield decline from the control plot to stoniness. Yield gap ranges based on the minimum and maximum threshold values showed that under certain erosion indicators farmers could be losing over 50% of their yields due to observed past or current erosion indicators in agricultural lands. The variability in yields among the erosion phases were better illustrated when overall mean yields were averaged over the study period (Fig. 4). Absolute yield gaps ranged from 1.51 - 3.17 ton ha^{-1}. Loss of more than 50% of the control conditions was already evidenced in fields in depositional zones (sedimentation) and fields with exposure of stoniness on the soil surface.

Despite the widescale belief by most farmers and scientists that areas in depositional areas are the most fertile landscape zones, this study disapproved that. Consistently in both the long and short rainfall seasons of 2003, fields in sedimentation soils were out-yielded by all other erosion indicators except stoniness. Lal et al. (2000) observed similar growing inconsistent superiority of sedimentation zones over the more eroded upslope fields in crop yields between years.

These observations could illustrate the importance of communal approach in planning and timely implementation of soil erosion control measures in both upstream and downstream areas within a hydrological catchment. Also, the study establishes that soil erosion attaining an erosion phase equivalent to stoniness could be the critical limit, beyond which crop growth is uneconomical. Such levels of soil degradation, according to Kilewe and Mbuvi (1990), could lead to partial or total loss of soil resource for crop production and whereby even addition of higher rates of inorganic and organic fertilizers might still prove uneconomical given the loss of soil rooting depth.

Table 5. Mean, minimum-maximum maize grain yields and yield gap ranges from fields under different soil erosion indicators in Gikuuri catchment, Kenya

		Maize grain yield (ton ha^{-1})		
Season[†]	Indicators[‡]	Means*	Min-Max	Yield gap range (%)
LR02	Control (12)	3.91a	1.78-10.89	0
	Rill-sheet (4)	1.88a	0.87-2.04	50-81
	Red soil (6)	2.63a	0.89-5.78	47-50
	Stoniness (5)	1.11a	0.20-2.44	76-89
SR02	Control (12)	4.72a	2.89-10.44	0
	Rill-sheet (4)	3.44ab	2.13-4.80	26-54
	Red soil (7)	2.13bc	0.67-4.67	55-77
	Stoniness (5)	0.64c	0.11-1.11	89-96
LR03	Control (14)	3.81a	2.00-7.56	0
	Rill-sheet (4)	2.56ab	0.30-6.13	19-85
	Red soil (8)	1.86b	0.67-3.11	59-67
	Sedimentation (8)	1.57b	1.00-3.11	50-59
	Stoniness (4)	0.92b	0.33-1.33	82-84
SR03	Control (20)	5.21a	1.78-8.89	0
	Rill-sheet (4)	3.84ab	1.12-6.40	28-37
	Red soil (16)	4.28a	1.56-8.00	10-12
	Sedimentation (6)	2.85ab	0.89-6.89	22-50
	Stoniness (5)	1.60b	0.89-2.67	50-70

[†] LR stand for Long rainfall and SR short rainfall; [‡]numbers in parenthesis are number of fields in which the crop yield was assessed from; [*]figures followed by the same letter are not significantly different at the 5% level

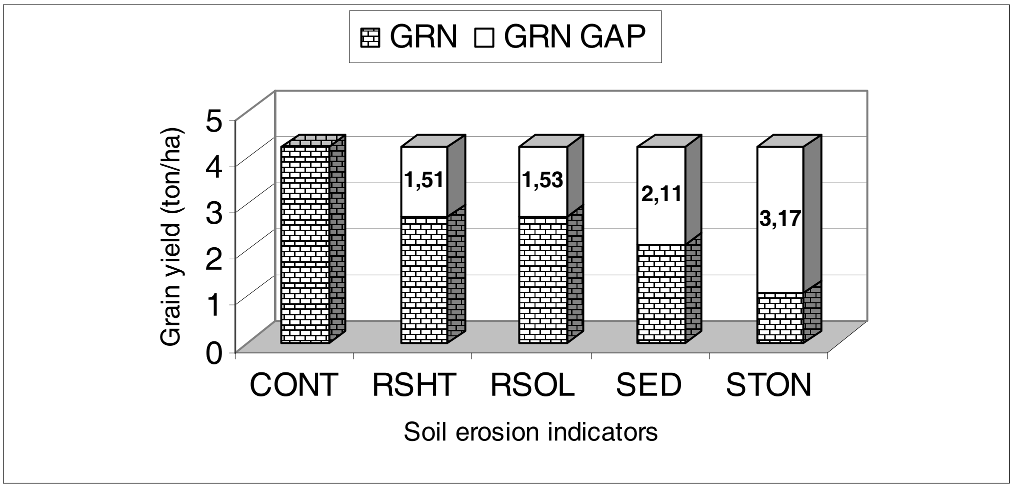


Figure 4. Average grain yields (GRN) and yield-gap (GRN GAP) levels (shown values) in soils under different erosion indicators as found in the farmers' fields. **NOTE**: **CONT=** is control or reference soils with hardly any visible erosion; **RSHT**=soils depicting sheet-rills-root exposure erosion condition; **RSOL=** red colour-loose textured soils due to loss of rich dark soils; **SED**=sedimentation zones; **STON**=stoniness soils.

Conclusion

The study shows the importance of rill-related attributes to estimate total soil loss, judging from the significant correlations between the developed rill attributes and measured soil loss. The study does establish that despite the insignificant correlation levels between topsoil profile depth and actual soil loss, the change in profile depth was positively correlated to soil loss though statistically insignificant. It also indicated that more of the eroded materials could be from rill sidewalls and its bed besides splash transported materials. The magnitude of change in topsoil profile was however controlled by the nature of rainfall intensity. Short rainfall season tended to generate lesser surface runoff volume, which was reflected in erosion-sedimentation pattern along the slope length than is realised during the more erosive long rainfall seasons. The rill development was also enhanced with time in the rainfall season. With further rainfall events the number of rills and rill length tended to increase in the downslope direction. This analysis strongly implied the need to counteract further development of sheetwash and rill channel indicators through increased soil-cover, against splash raindrop impact, and conservation measures to reduce slope length.

It was the intent of this study to quantify the soil erosion indicators, predominant on the agricultural hillslope areas. Matching the rills and splash pedestals formed during rainfall events to the resultant soil loss resulted in two feasible linear regression equation models. These equations underscored the importance of using rill length, rill width and depth, and splash pedestal height variables in erosion estimation. Of these variables, rill length showed more influence to the measured soil loss than the rest. However, use of these models without considering rill-related variables might under-predict soil loss rates, given the poor sheet erosion (i.e. splash pedestal height) response to the total soil loss. These results therefore show that dimensions of the rills and splash pedestals, as the major indicators of current erosion process, could be useful in estimating soil loss rates when employed in regression equations. These equations are simple and can be used by field-workers without requiring much time in data collection. On the other hand the variables in the equations may not be limited to specific climatic and topographic conditions that most often limit widescale use of complicated models or extrapolation of site-specific runoff data. The indicators of splash raindrops and rill erosion processes are widely observable on agricultural lands hence the high potential in use of these regression equations, but only at field scale.

There exists a good correlation between crop yields and the onsite erosion phases observed in the farmers' fields and which affected crop yield remarkably. Crop yields from the control soils out-yielded all eroded fields by between 10-96 percent. The consistence in crop yield declining gradient from control soils to soils exhibiting surface stoniness implied that one was capable of predicting or assessing approximate crop yield levels from the superficially expressed soil erosion indicators. Apparent observation was that the crop yields continued to diminish increasingly with the removal of topsoil by water erosion.

However, other important findings were that the soils in valley bottoms with sedimentation phenomena and those with exposure of stoniness were at great risk of being abandoned from meaningful crop production. These soils are currently experiencing more than 50 percent maize grain yield loss despite addition of organic and inorganic fertilizers and use of recommended planting seeds. From this study and others that have confirmed the spatial widespread of similar soil erosion indicators in the steep highlands of East Africa (Okoba *et al*., 2003) the likelihood of maize yield to decline below the potential levels (3.5 ton ha^{-1}) is high. Therefore to arrest further degradation of soils that have not lost its sustainability for crop production, the study appeals for the need to mobilise the farming community to get involved in estimating the extent of soil erosion damage on their own fields upon which they shall be motivated to voluntarily implement conservation measures where appropriate. Otherwise lack of it would subject downstream or neighbouring farmers to untold longterm suffering because of the off-site effects due to over-laying of nutrient-rich soils with nutrient-poor soils from the upslope fields besides other possible damage to infrastructures.

Acknowledgment

We wish to acknowledge the Eco-regional Methodological Fund program at the Haque (The Netherlands) for funds to undertake this study. Guidance on linear regression modelling from Mr. John Kuwornu and Ms. Beatrice Salasya of the Social Science Group of Wageningen University was highly appreciated. Assistance received from Mugo Rimui and Leonard Musiega of KARI-Embu during data collection and the objective criticism from the PhD discussion team of the Erosion and Soil and Water Conservation Group of the Wageningen University were appreciated.

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Chapter 5

FARMERS' ESTIMATES OF SOIL EROSION AND CROP YIELDS COMPARED WITH SCIENTIFIC ASSESSMENTS IN THE HIGHLANDS OF KENYA

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Submitted to: Agriculture, Ecosystems and Environment (2004)

Farmers’ estimates of soil erosion and crop yields compared with scientific assessments in the highlands of Kenya

Abstract

Soil and water conservation programmes in Kenya though several decades old they have not shown widescale success in increasing agricultural productivity. This can be attributed partly to experts’ negligence of the role of farmers in problem identification and conservation planning preferring scientific approaches. Scientific mapping and interpretation tend to provide recommendations that disagree with farmers’ perceptions. Adopting the use of farmers’ knowledge of soil surface morphology to assess soil productivity can stimulate farmers to participate in solving the prevailing problems on their own terms. Their perspective of soil degradation can form a good basis to compare with scientific approach that estimate soil erosion based on topsoil erosion features. The objective was to compare soil erosion and crop yield estimations by farmers’ knowledge with a scientific approach in Kenya. Farmers’ knowledge and perceptions of the effect of topsoil erosion features was used to assess the soil erosion status across the catchment area whereas scientific evaluation was done using rills and sheet erosion features firstly along the four transects and then upscaled to catchment, based on slope steepness only. Farmers’ qualitative estimation of crop yield loss was verified through experimental measurements. The spatial erosion patterns between the two approaches were compared using cross tabulation and the degree of agreement was evaluated using kappa coefficient analysis in the SPSS program. The soil erosion pattern between the farmers’ and scientific approaches showed a strong agreement (a kappa value of 0.478 at $P<0.01$) at transect scale and at the catchment scale the agreement was slightly weaker (a kappa value of 0.272 at $P<0.001$). Matching the erosion patterns between the two approaches showed a correct match accounting for 56 percent of the catchment, but increased to 92 percent when a one-class mismatch error was accepted. Farmers observed more area under flat and gentle slopes to have high erosion than the area approximated by scientific evaluation, which could be attributed to the inherent difference in the concept of erosion evaluation. Farmers’ prediction of crop yields loss in each erosion class showed no difference with the actual field measurements. Spatial accuracy of scientific erosion assessment can be improved by integrating some aspects of farmers’ perceptions.

Keywords: *Farmers’ knowledge; Soil erosion status; Crop yield loss; Kenya.*

Introduction

Population pressure in the central highlands of Kenya has been associated with intensive use of land and poor farming practices that do not consider the replenishing of soil-nutrients and counteracting soil erosion problems. Consequently these practices have directly contributed to declining agricultural production, rural livelihood standards, quality of water bodies in the downstream areas and volume of perennial river flows. To alleviate the environmental situation, strategic soil and water conservation (SWC) programmes were initiated in the 1970s by the Kenyan Government

(Pretty *et al*., 1995). These programmes attempted to mobilise farming communities using various participatory methodologies to adopt labour-intensive SWC measures on their farms (Wenner, 1981; Wenner, 1988). However, during implementation of the programmes the determination of the extent of soil erosion did not consider farmers' indigenous knowledge (Pretty *et al*., 1995) but used "foreign" empirical models and conservation measurers (e.g. Wenner, 1981). Past studies have shown that the soil erosion susceptibility maps that consequently influenced landuse plans in Kenya relied largely on qualitative ratings of factors of the Universal Soil Loss Equation (USLE) (e.g. Thomas *et al*., 1997; Wanjogu and Mbuvi, 2000). Given the widescale variability of rainfall, topography and soils in the central highlands of Kenya, use of the generalised USLE factors to derive suitable land use recommendations tended to mismatch with what is considered realistic in a field situation and preferred by farmers. Because of these, the implemented SWC measures did not end the problems of soil erosion and low crop yields, thus leading to farmers' lack of interest in maintaining or adopting further measures (Shaxon, 1988; Scherer, 1989).

One of the reasons for widespread low adoption of conservation measures by farmers was attributed to experts' lack of recognising farmers' perceptions of the land management (Shaxson, 1988). Specifically, farmers failed to adopt and even maintain the measures when implemented because the recommended measures did not accommodate their agronomic and economic aims. But also they were dissatisfied with how erosion hazard was mapped and interpreted, failing to pay attentions to their landuse and management preferences and socio-economic status. The consequence of their dissatisfaction was apparent when experts' plans were adopted and did not show evidence of influencing a decline in soil loss and crop production (Stocking, 1985). Others have looked at the farmers as a part of the solution to the environmental problems and hence recommended for their involvement right from the beginning of SWC programmes in order to ensure that their full participation in defining the problems is achieved (Hudson, 1988; Shaxson, 1988). However, based on farmers' great sense of the cultivated landscape, their knowledge of soil surface morphology can be useful; both for evaluating the status of resources use (Conway, 1989) and to validate the accuracy of the conventional land management planning approaches that may not be designed for the local conditions. Farmers' widespread knowledge and perceptions of the landscape can also allow them to diagrammatically model their local physical environment revealing the "hot spots" that may require improved management, but also picturing current resource-use practices (Gupta, 1989). Farmers' knowledge of ecological processes, more or less unknown to academic researchers, is becoming respectable as a potential means of enriching scientific knowledge (Critchley *et al*., 1994). Habarurema and Steiner (1997) noted that whereas scientists assessed the soil suitability on basis of different soil strata, farmers restricted themselves to the topsoil (A-horizon) profile. According to the farmers, crops heavily exploited this stratum and they therefore closely related it to the resulting crop harvests and soil suitability (Gupta, 1989).

Despite widescale awareness of the significance of farmers' knowledge, how it can be used to estimate current erosion status and associated crop yield levels in comparison to the scientific assessments has not received much attention. Therefore the objective of this paper was to compare soil erosion and crop yields estimates according to the farmers' knowledge with a scientific approach in the highlands of Kenya.

Materials and Methods

The study area was sited in an intensively cultivated area that represents the typical smallholder farming systems in the high rainfall highlands of Kenya. Gikuuri catchment (at 00^0 26´S 37^0 33´E) in Embu District of Kenya, with a land area of about 500 ha was selected. It has an altitude range of 1302-1500 m and a population of about 657 households spread across the seven villages. Annual rainfall is about 1270 mm, of which 47% comes in March-May (long rains) and 38% in October-December (short rains). The months between the rainfall seasons are either dry (January and February) or cooler (June-August). Daily average temperatures fluctuate between 10^o and 28^oC during the year. Because of the reliable rainfall pattern and potentially fertile soils, farmers have adopted several cropping systems. The adopted crops can be identified on certain topographic niches of the landscape. Whereas maize, beans and coffee are mostly on the moderate-steep (12-30%) hillsides, bananas, sugarcanes and vegetables are predominantly preferred within the homestead and in the valley bottom areas where permanent river flows assure irrigation water in dry seasons. *Miraa* or Khat (*Catha edulis*) shrub could be planted either next to the homestead or near the water source whichever is safer since the shrub is a fast source of farm income and therefore prone to theft. Woodfuel and/or timber-based trees and the fruit trees are planted along the farm as boundary markers and as windbreakers around the homestead. Growing of Napier grass is extensively practiced, as strips and in blocks, because of its double importance for erosion control and as a valuable livestock fodder.

The characteristic properties of the six soil types found in the area are shown in Table 1. They have a dusky red to dark reddish brown colour and are of a friable to firm consistence. Their structure is largely described as strong, very fine to medium and, crumby-weak and medium sub-angular blocky aggregates (Wanjogu, 2001). Cultivation has been carried out continuously on these soils for several decades so that soil structure is becoming weaker and soil nutrient replenishment is needed if significant crop production is to be realised. Tillage is undertaken using hand tools following a characteristic up-down tillage operation. This effectively enhances surface runoff in the downslope direction and increases soil loss, stimulating land degradation. Common cultural practices farmers employed for countering the low soil fertility is the application of farmyard manure or leaving crop residues *insitu* (Murage *et al*., 2000). Despite these efforts soil fertility has not improved and crop production is marginal due to failure of most farmers to check surface runoff; common in the cultivated hillslopes in the highlands (Roose and Ndayizigiye, 1997; Wanjogu, 2001).

Methodology

In order to address the objective of this study several steps were taken. The researchers and extension officers invited the village leaders from each of the seven villages for a meeting to discuss the mapping of soil degradation in their respective villages. To ensure that fair judgement of the erosion mapping was made, all the seven village leaders were asked to identify 2 to 3 other farmers to form the village key informant teams. Those selected must come far apart from each other within their respective villages.

Table 1. Chemical and physical description of soils in Gikuuri catchment, Kenya.

	Chemical characteristics^{+}					Texture class^{+}(%)			Soil depth
Soil types	pH	Total N (%)	P (mg kg^{-1})	K (me%)	Total org.C (%)	Sand	Silt	Clay	Top-soil (cm)
rhodic Nitisols	4.5	0.13	18	0.84	1.8	12	13	75	0-20
haplic Acrisols	4.8	0.15	13	1.01	2.0	10	2	88	0-16
chromic Luvisols	5.1	0.07	15	1.25	1.3	8	6	86	0-15
chromic.Luvisols/Cambisols	4.7	0.11	22	0.95	1.5	8	10	82	0-20
dystric Gleysols	5.0	0.12	19	1.15	1.3	4	12	84	0-30
dystric Fluvisols	4.7	0.10	11	1.08	1.7	6	8	86	0-10

$^{+}$Methods used to determine these elements: soil acidity (pH) was in 1:1-H_2O suspension; total nitrogen percent (N) by Kjeldahl digestion; total phosphorus (P) by Mehlich-one extraction process; potassium (K) by flamephotometric and total organic carbon percent (C) by Walkley-Black dichromate. Textural separation was by hydrometric method (Hinga *et al*., 1980; Anderson and Ingram, 1993).

This was to ensure that they were able to assist each other in recognising different neighbourhood fields and village boundaries during participatory field mapping exercises. Once the teams were established a public meeting was organized for all the villagers. During the meeting the key informants undertook to sketch on the ground the outline of the catchment area, and showing all the household field boundaries in each village. Once the catchment fields map was completed and unanimously agreed upon by all the attendants, the key informants compiled the list of the field owners in their respective villages. The extension officers and the researchers then copied the sketched catchment map from the ground to a large sheet of paper, which was consequently verified as true copy of the catchment field map by the key informants.

The next activity was for the farmers to conduct field-by-field survey of soil erosion status using the erosion indicators evident on the soil surface. Previous studies by Okoba and Sterk (2004) reported that farmers in this area had identified eleven types of soil erosion indicators that were widespread on the landscape. In order of relative severity ranking according to farmers' perceptions, from high to low severe, these indicators were: gullies, breakage of SWC structures, stoniness or gravel on soil surface, topsoil turning to red colour, rock exposures, rills, root exposure, sedimentation, smoothened soil surface due to sheetwash, splash pedestals and soil structure turning loose. Therefore the key informants visited all the fields and enumerated the existing erosion indicators. The impact of the observed erosion indicators on crop yield was also assessed on field-by-field basis. Survey of the erosion indicators covered all the villages in two cropping seasons (Oct.-Dec. in 2001 and March-May in 2002). The two surveys were to ensure that the prevalence of erosion indicators on the visited fields was certain. The survey was carried-out immediately at the end of every rainfall season i.e. the months of May and December. This was an appropriate period to evidence the impact of previous rainfall and past erosion damages before the commencement of routine seasonal digging of the fields after crop harvesting.

Tabulated data sheets for the field surveys were prepared to ensure that the key informants could undertake the recording of the observation without extension officers or researchers' involvement. Details of data to be recorded included name of the field owner, the name of the village, erosion indicators observed per field and prediction of crop yield loss in view of the extent of soil erosion indicators present. The predicted crop yield loss was scored on a scale of three classes. The high yield loss was where the key informants anticipated a loss of 100-50% (whole to half), moderate was for 50-25% (half to a quarter) loss and low for less than 25% (below a quarter). These were arbitrary ranges set to evaluate crop yield decline due to the effect of soil erosion processes.

After the second seasons survey the key informants revisit only the fields that exhibited soil erosion indicators. The goal was to indicate on the catchment fields map the extent of soil erosion damage on basis of the observed erosion indicators. Every key informant team therefore visited all fields in their respective villages and determined the soil erosion damage judging from the intensity of erosion indicator and its spatial extent. Farmers' estimate was based on the number and types of erosion indicators they detected and on their spatial distribution. Where the whole field was found to have a uniform distribution of the observed erosion indicators, the key informants made estimates on the overall status of soil erosion. But where erosion indicators were not uniformly distributed over the field, a boundary was marked separating between the differently eroded sections of the field and for each section the seriousness of soil erosion was assessed. This was scored in three classes: low, moderate and high. The extent of soil erosion was assessed first on the land and then marked on the field map by the key informants. Figure 1 illustrates how spatial extent of erosion indicators and soil erosion status were distinguished and classified. The outcome of this exercise was a map representing the status of soil erosion per household field in the catchment, according to farmers' knowledge and perceptions.

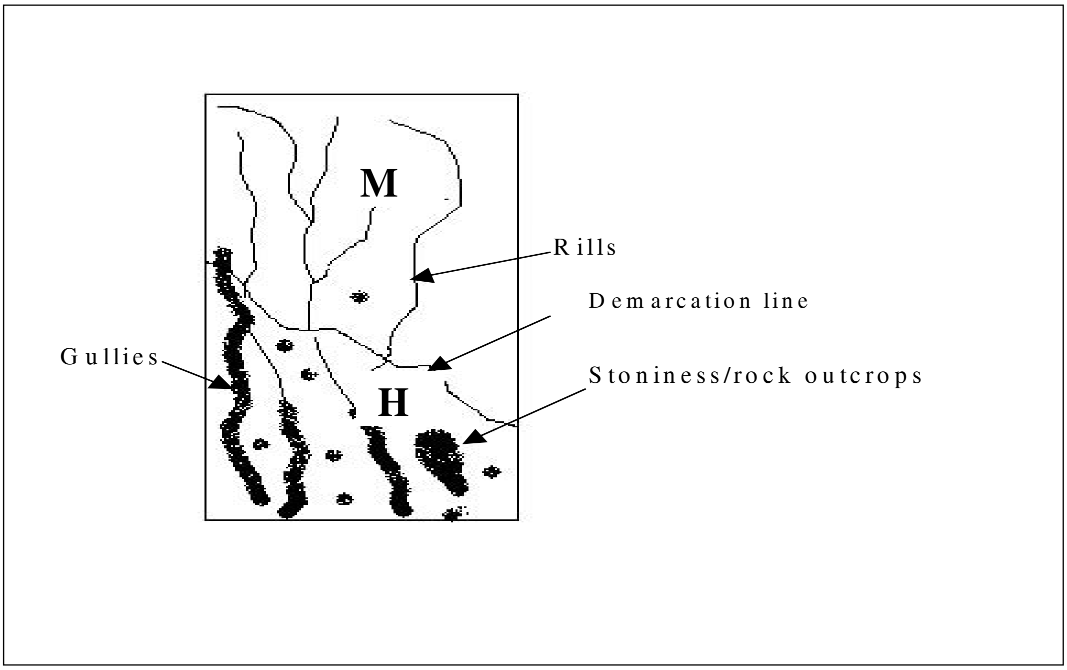

Figure 1. An illustration on how farmers delineated a field into high (H) and moderate (M) soil erosion classes on basis of the spatial distribution and perceived severity of the shown soil erosion indicators.

At the end of the erosion assessment by the key informants, the catchment erosion map was then drawn on a large cloth, which was presented to all the seven villages during a public meeting, in the study area. This was to ensure that all households in the catchment could identify their fields and verify the allocated soil erosion classes. Once consensus on erosion classification was achieved around all the villages, GIS software (Arcview-Arcinfo and PCRaster; Wesseling *et al.*, 1996) was used for digitisation and storage of the map into electronic format, which would be used for comparing its soil erosion patterns with a soil erosion map by a scientific approach.

The scientific approach was based on the monitoring of soil loss due to sheet and rill erosion along four (4) transects in the catchment area. To do this, the researchers delineated the catchment map into topographic units representing a sequence of flow elements starting from the drainage divide to the valley bottom, using the contours on the topographic map. Each element represented different slope steepness and flow direction. The locations of the delineated elements were identified on the land as guided by the river streams, valleys and the old roads on both the land and the topographic map. The transects were selected in different areas within the catchment; depicting various combinations of the typical slope steepness and landuse types based on field observation. Each transect path, of 3m wide, was clearly marked starting from the drainage divide to the valley bottom using wooden pegs thus crossing through several slope units (elements). The description of the four transects is shown in Table 2. The valley bottom elements were not considered since not all transects had clear distinguishable valley bottoms.

Table 2. Description of the elements in each of the transect surveyed in Gikuuri, Kenya

Transect No.	Element slope class[†]	Total element length (m)	Landuse types
1	Gentle	43	Maize and beans
	Very steep	83	Coffee and beans
2	Steep	56	Coffee, maize and beans
	Very steep	147	Coffee and maize
3	Gentle	177	Maize and beans
4	Flat	45	Maize and beans

[†]Element slope classes: Flat=<6%, Gentle=6-15%, Steep=16-32%, Very steep=>32%.

Sheet erosion was quantified using erosion pins that were installed within all the elements of the transects. Six erosion pins (made of bicycle spokes) were installed randomly across the width and length of the elements to estimate soil loss through sheet erosion process. An erosion pin was pushed into the ground to halfway its height (30 cm) and its mid point was marked with water proof ink pens, which was the reference point in determining the topsoil profile changes whenever an erosive rainfall event occurred. The rill erosion was quantified using the Assessment of Current Erosion Damage (ACED) method (Herweg, 1996). Within every element of the transect, rill erosion was estimated by measuring rill depth, width, length and number of rills from which volume of the rills was calculated. Monitoring of both the sheet erosion (sedimentation or soil loss) and rill incision (small channels) were carried out during the same time. The measurement campaigns were carried out in two rainfall seasons: March-May and Oct.-Dec 2002. In every season two surveys were carried out after installation of the boundary pegs marking the transect paths in selected hillslopes. First survey was carried out in the middle of the rainfall season (April and November) and the second survey at the end of the season (May and December).

The average topsoil bulk density in the transects was determined by sampling the topsoil layer (5 cm deep) using 100 cm^3 ring sampler and measuring dry mass of the soil after overnight oven-drying at 105^oC. With reference to the element area within the transect, the total volume of rills, the topsoil decline depth (sheet erosion) and soil bulk density, the annual soil loss (ton ha^{-1}) was determined. Three soil erosion classes (low, moderate and high) were defined to categorize the soil erosion in qualitative form like the farmers' estimations.

The catchment soil erosion map based on delineated elements i.e. the slope classes was a result of extrapolating element soil erosion classes, within the transect, to the catchment scale. This map was overlaid to the catchment map showing individual field holdings as drawn by farmers, resulting in an erosion map showing erosion status for each individual field. These steps were executed using GIS Arcview-Arcinfo and PCRaster, thus producing catchment soil erosion class map based on the scientific approach. At this point, the erosion maps based on scientific and farmers were evaluated for their agreement purely on erosion class patterns. Firstly the cross tabulation analysis (in SPSS) to check on erosion classes was used to evaluated the soil erosion patterns within the transects by scientific approach against the estimates by farmers, but for the overall accuracy of agreement in predictions, kappa coefficient of determination analysis of the SPSS program was applied. First, it was evaluated how well the farmers' estimates of erosion compared with the scientific assessment at the transect level. Then, if this yielded sufficient agreement, upscaling of the scientific approach would be tried and used to evaluate the accuracy of the farmers' soil erosion map at catchment scale.

Secondly, the agreement between soil erosion catchment map by scientific approach and farmers' estimation was measured using the difference map between them. The difference was obtained by subtracting the farmers' soil erosion map from the scientific soil erosion map. The characteristics of the difference erosion map were illustrated using percentage areas that were either matched correctly or under/over-predicted erosion classes. Further insight in the two maps was obtained by assessing each area of slope classes falling under each of the three erosion classes.

The study also carried out a field-based experiment to quantify the farmers' qualitative predictions of crop yield loss. Therefore samples of fields classified as having high, moderate and low crop yield loss (during erosion indicator survey), and falling within the respective soil erosion classes were selected across the catchment. Also fields on hill summits, which have not experienced any significant erosion (control), were identified and selected. These were to be used as reference fields for determining the actual relative crop yield loss (or yield gap) in low, moderate and high crop yield-soil erosion conditions. Therefore, samples of fields were selected for the quantification of farmers' prediction of crop yield loss. At the beginning of the study the researchers, together with some key informants selected 18 fields perceived to have high soil erosion and high yield loss, 20 fields in moderate soil erosion and moderate yield loss, 18 fields in low soil erosion and low yield loss and 14 fields perceived as control. The spatial distribution of the selected fields within the catchment area is shown in figure 2. During the three rainfall seasons (October-Dec. 2002 and March-May and Oct.-Dec. 2003) maize crop was planted in the selected fields and managed by farmers while the researchers provided all the necessary inputs for the experiment. In each of the fields, a plot of maize crop measuring 4m by 4m was marked-out and harvested on attaining physiological maturity (3.5 months after date of planting). The mass of the grain yields was standardized at 13 percent moisture content before calculating the average yield loss per crop yield-soil erosion class combination. The crop yield loss was calculated as a percentage of the relative proportional difference between crop yield in the soils perceived as eroded and those from control fields.

Further validation of the farmers' estimation of fields as having low, moderate or high crop yield-soil erosion classes was carried out using soil chemical analysis of the *insitu* topsoil. Composite topsoil (15cm) samples from each yield-erosion class and control soil were collected and analysed for nutrient levels of total nitrogen (N), total phosphorus (P), potassium (K), total organic carbon (C) and the soil pH. Methods used in the soil analysis were the standard chemical and physical soil analysis used at the Kenya Agricultural Research Institute Laboratories at Kabete, Nairobi. Organic carbon determination was by Walkley-Black dichromate method, and total nitrogen by Kjeldahl digestion method using calorimetric procedures. Available phosphorus was determined by Mehlich-one method, pH was analysed in 1:1-H_2O suspension, and potassium was determined using the flamephotometric method (Hinga, *et al*., 1980; Anderson and Ingram, 1993).

Figure 2. Gikuuri catchment field map showing the selected fields (marked in grey) for evaluation of crop yield levels.

Results and discussion

During the two periods of the erosion assessment campaigns on rill and sheet erosion within the transects, it was noted that the long rains (March-May) caused more erosive runoff events due to higher rainfall intensities (>25 mm hr^{-1}) than during the short rains (October-December) (Van der Wielen, unpublished) therefore resulting in washing off of rills that had been identified during the previous campaigns. In such cases we experienced high exposure of erosion pins, sometimes finding crop residues trapped onto the erosion pins. Despite the low rainfall intensities during the short rains more sheet erosion than rill incisions especially on gentle and flat slopes was observed. We did not consider second set of data (second rill and sheet survey) in the elements where previous rills had been destroyed by overland flow or when overland flow was too heavy that erosion pins had been severely interfered with.

Comparison of soil erosion patterns at the transect scale

Thought the total number of rills and length within each element seemed to be influenced by the slope steepness, the depth of topsoil removed by sheet erosion did not differ between elements (Table 3). The rills did not vary with land use pattern in each element. Because SWC measures were not uniformly laid out in all transects at regular intervals within the elements, their influence was not considered in this study. Though ideally SWC measures were expect to exists in coffee fields especially on steep and very steep elements (refer to Table 2) yet this is where the highest incidences of both the rills and sheet erosion were noticed (Table 3). Generally whether the crop cover within the elements was intercrop of coffee and maize and/or beans there were no large numerical differences in the amount of soil loss. Possibly because severe erosion tended to occur at the on-set of the rainfall season than later when the percentage soil cover was high and rainfall was reducing during the growing season. Erosion pins exposure tended to be extremely high on both the steep and flat slopes (between 0.06-0.68 cm) suggesting either the effect of runon due to external runoff sources and upslope hillslopes or ease of topsoil removal at the onset of the rains.

Table 3. Average number of rills and topsoil decline in the elements of the four transects

Transect	Element slope	Total number of rills	Total rills length (m)	Mean topsoil decline (cm)
1	Gentle	35	77	0.06
	Very steep	37	135	0.38
2	Steep	46	97	0.40
	Very steep	46	122	0.25
3	Gentle	36	78	0.68
4	Flat	19	48	0.42

Given the above observations the annual soil loss was averaged on basis of similar element classes but not landuse types in the four transects. The soil loss ranged from 17 to 121 ton ha^{-1} per year (Table 4). The highest erosion rates were in very steep slopes (in transect 1 and 2) whereas relatively low erosion in flat and gentle elements. The soil erosion rates were categorized into three arbitrarily chosen classes to match the farmers' qualitative erosion scales of high, moderate and low. The three soil erosion rates were the low (<17 ton ha^{-1} per year), moderate (17-47 ton ha^{-1} per year) and high (>103 ton ha^{-1} per year). In qualitative terms these categories were compared to farmers' predictions of soil erosion status along the same transects (Table 5). The erosion classes by both approaches were correctly matched in most elements of the transects except in two transects. Further comparison of these two approaches showed a significant agreement (P=0.098) at a high kappa coefficient value (Table 6) despite the mismatch shown earlier in transects two and four (Table 5). Whereas the scientific approach assigned both elements in transect two to high erosion class, the farmers under-estimated in the steep slope element by two-classes hence assigning it to a low erosion class. Similarly a mismatch in transect four was because farmers over-estimated in transect four by one-class. While one class difference can be assumed as a minor error, the two-class difference could have serious implication when such a judgement is to lead to land management decisions. Therefore the agreement between the two approaches along the transect scale allowed further testing at the catchment scale.

Table 4. Summary of scientific soil erosion assessment at the transect scale within Gikuuri catchment, Kenya.

Slope gradient Class	No.elements represented	Avg. soil loss ($t\ ha^{-1}$per yr)	Erosion class
Flat (<6%)	1	17	Low
Gentle (6-15%)	2	47	Moderate
Steep (16-32%)	1	103	High
Very steep (>32%)	2	121	High

Table 5. Soil erosion classification along the transects by farmers' and scientific approaches in Gikuuri catchment, Kenya

Transect	Number of Elements*	Soil erosion classes according to‡	
		Farmers'	Scientific
1	1 (gentle)	2	2
1	1 (v.steep)	3	3
2	1 (steep)	1	3
2	1 (v.steep)	3	3
3	1 (gentle)	2	2
4	1 (flat)	2	1

* The descriptions in parenthesis are the element slope classes; ‡Erosion classes: 1=low, 2=moderate, 3=high.

Table 6. Evaluation of agreement between scientific and farmers' prediction at the transects and catchment scales using kappa coefficient test, Gikuuri catchment, Kenya

	Scientific	
	Transect	Catchment
Farmers'	0.478	0.272
P-levels	0.098	0.001

Farmers' soil erosion assessment at the catchment scale

The farmers' assessment and classification of soil erosion status, based on the extent and effect of the soil erosion indicators at field level was aggregated to result in a catchment soil erosion patterns map (Fig. 3A). This shows the erosion level assigned by farmers on basis of the observed indicators on the soil surface. Moreover the villagers verified the portrayed erosion pattern confirming that it reflected the realistic condition on the ground. This assessment points at the farmers' remarkable sense of awareness of the impact of soil erosion on the soil productivity. The high erosion class was clearly perceived to represent fields that yielded least crop harvest and were associated to erosion indicators such as gullies, stoniness, rock outcrops and loose soil texture (field data not shown). But fields depicting rills and sheetwash indicators or had SWC measures installed were perceived to having low indication of erosion damage. The on-site final consensus on the erosion status by the key informants was arrived at on basis of the surface erosion indicators, the slope steepness and the state or potential of crop growth. From the farmers' map of erosion, high soil erosion tended to strongly coincide with steep and very steep slopes, but also depicted the presence or absence of SWC measures (data not shown). Fields classified as having low erosion were generally found in terrains that are not of steep gradients or where influence of SWC measures improved crop yields (one of the many indicator of low erosion). Tendency for farmers to refer to both physical erosion indicators and corroborated by crop performance is common. Such observation was reported of Tanzanian farmers in West Usambara Mountains, who used poor crop development and seed germination to judge the state of soil erosion (Okoba *et al*., 2003). Unlike other studies, which have used farmers' knowledge to distinguish between different soil fertility levels (Murage *et al*., 2000; Mango, 2000; Desbiez *et al*., 2004), this study observed that farmers had well defined soil erosion indicators to assess and classify overall soil damage on their cultivated fields. They used these to distinguish between cultivated areas with different soil productivity. This shows that there are close interrelationships between soil erosion indicators and loss of soil fertility, especially given that water erosion directly impacted on soil profile, leading to increased loss of plant-nutrients and reduced plant-rooting depth.

From the farmers' erosion map, it is apparent that erosion pattern did not distinguish between valley bottoms and the neighbouring upslope fields. This was because individual landholdings extended from upslope to the riverbanks, thus incorporating valley bottom segments into the fields immediately upslope. Most valley bottom fields were not as productive as they ought since the topsoils were mixture of various sediment materials originating from the upstream nutrient-poor surface soils.

Comparison of soil erosion patterns at catchment scale

After establishing a good match between the scientific and farmers' soil erosion patterns at the transect scale (Tables 5 and 6) it was justifiable to scale up the results of the scientific approach from transect to catchment scales (Fig. 3B). This was only based on slope steepness (i.e. flow elements) given the lack of differential influence of landuse types observed at all the transects in soil erosion rates (refer to Tables 2 and 3). The test of validity of agreement between the farmers' and scientific soil erosion pattern maps at catchment scale depicted a significant relationship ($P<0.001$) and a positive kappa coefficient of correlation (Table 6). An alternative analysis of agreement between the two approaches was better comprehended through assessment of the difference in patterns of erosion classes. We assumed the scientific approach to be the realistic map, which depicted the soil erosion status in the field and to which the validity of the farmers' soil erosion assessment was to be checked. This resulted in a difference map (Fig. 3C); obtained by subtracting the farmers' erosion map from the scientific erosion map. The descriptive analysis of Figure 3C is shown in Table 7. The correct matching, i.e. class-to-class, between the two approaches accounted for the largest area (56%) of the catchment, the rest of the catchment area was accounted for by a mismatch of erosion patterns of one-class (36%) and two-class (8%) difference. The majority of the correctly matched classes or patterns were detected to have come from the fields perceived to be under moderate and high erosion classes, implying that the one-class over/under prediction (36%) was misjudged between low and moderate erosion classes.

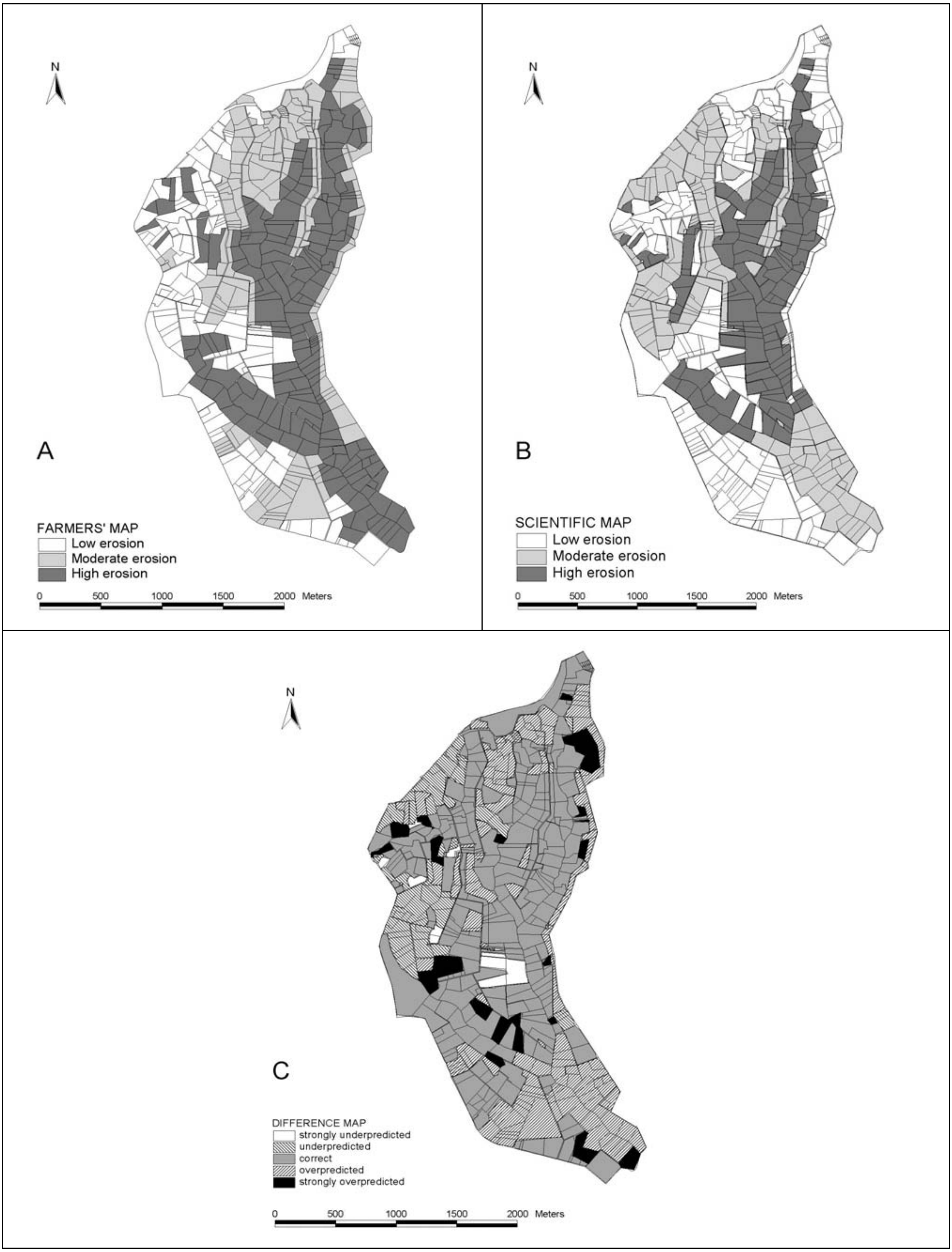

Figure 3. Gikuuri catchment soil erosion maps and the difference (C) between scientific (B) and farmers (A) estimates.

Table 7. Characteristics of the difference map between erosion patterns by farmers' and scientific approaches in Gikuuri catchment, Kenya.

Difference levels with respect to farmers	Area (m^2)	Area (%)
2-class under-predicted	123,200	2
1-class under-predicted	564,000	10
Correct match	3,100,000	56
1-class over-predicted	1,404,400	26
2-class over-predicted	338,800	6

We also compared the results of the farmers' with scientific soil erosion evaluation approaches at catchment scale by assessing the distribution of the erosion classes on different slopes (Fig. 4). Both approaches generally showed that a larger proportion of the slope area in steep and very steep slope gradients were under high erosion. However, the two approaches showed some significant difference in slope area proportionality and erosion classification in the flat and gentle slope gradients. In the flat slope gradient, the farmers' approach observed high erosion to account for more than twice the slope area the scientific approach allocated to high erosion. Remarkable differences were apparent in gentle slopes where largest area of the slope was perceived to having high erosion by farmers whereas scientific approach estimated the largest area to having low erosion. According to farmers the soil erosion status was getting severe even in areas presumably safe (e.g. flat-gentle slopes) and technically perceived not susceptible to soil erosion and therefore not requiring soil conservation measures. But this interpretation could also underscore on the factors farmers considered when estimating soil erosion status besides looking for soil erosion indicators visible to the naked eye. Though they were to deduce soil erosion status on physical indicators they also crosschecked their judgement by referring to on-site crop performance. However, poor crop performance could also have come as a result of other soil degradation agents, such as leaching and nutrient mining through crop stover removal (Kapkiyai *et al*., 1999). Though farmers have been known to be able to distinguish between fertile and infertile soils (Murage *et al*., 2000) it was not clear whether they knew the differences between infertility caused by soil erosion and nutrient loss through leaching or crop residue removal. Some studies have reported that farmers perceived soil erosion as the cause of soil infertility and hence considered poor crop performance as an indicator of soil erosion (Waswa *et al*., 2002; Okoba *et al*., 2003), especially where physical features of erosion were not evident. Therefore on basis of these observations it could be concluded that the farmers showed more rationality in judging soil erosion status than the scientific approach, applied in this study, mainly because of using linear extrapolations across a complex landscape (Fig. 4).

Consequently, though there were slight disparities in the procedures of estimating soil erosion status, a strong agreement in erosion patterns by both approaches was evident, rising from 56 to 92%, if one-class mismatch was considered as an acceptable error of estimation process. Therefore the two-class over-or under-prediction by farmers could have been due to their realistic interpretation of the soil conditions in terms of its current productivity. Use of transect values to upscale to catchment on basis of slope characteristics at the transect failed to recognise some counter erosion measures on very steep slopes or the highly eroded areas though on less steep slopes.

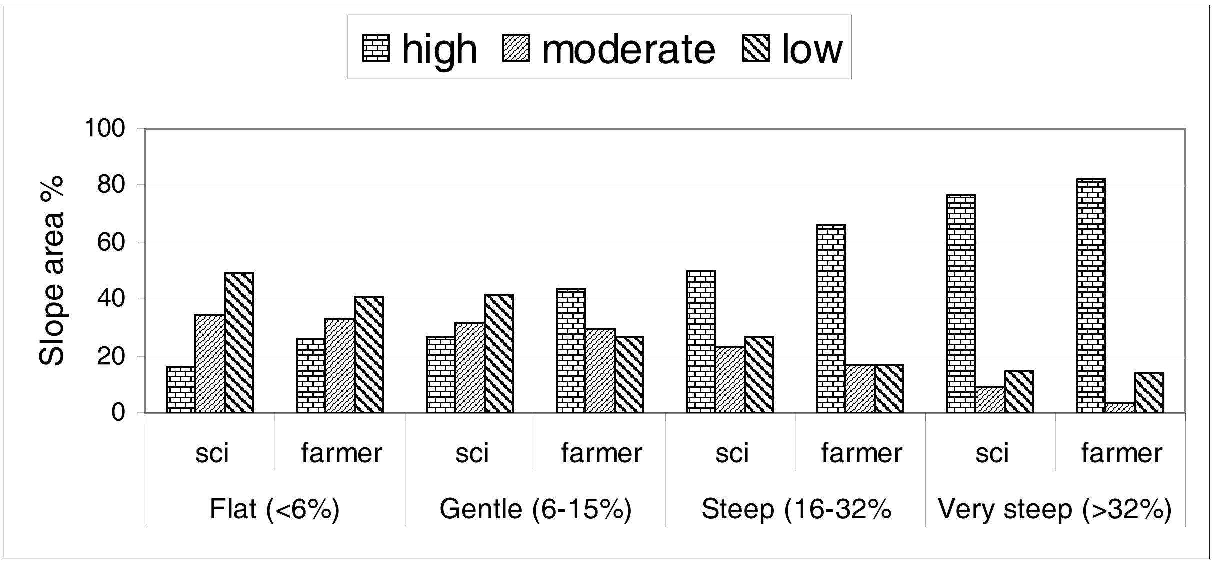

Figure 4. Comparison of erosion classification with respect to percentage area per slope steepness using scientific (sci) estimates and farmers' predictions in Gikuuri catchment, Kenya.

This was because of relying on data from four transects to upscale to catchment level; illustrating the inherent difficulties in plot data transferred to catchment scale with complex landscape characteristics. Implying that transect characteristics need to encompass all catchment attributes if the extrapolation was to provide realistic scenarios. Unlike the scientific use of transect to estimate the catchment erosion status, the farmers' catchment erosion map was based on field-by-field survey across the entire catchment thus providing a realistic erosion scenario.

Therefore our earlier assumption that the scientific approach was the realistic map on which basis farmers' erosion estimation would be checked from couldn't uphold. Instead farmers' knowledge and perceptions of soil erosion status need to be considered for improving accuracy of scientific approaches that estimate soil erosion at hillslopes or catchment scales relying on extrapolated datasets. This is so because farmers' interpretation of soil surface tends to be site-specific and rational and can be used in identifying land management problem areas though lacking underlying scientific explanation. However, where scientific approaches have been applied to generate spatial erosion scenario there is need for the farmers to approve the truthfulness of such a map prior to founding landuse policies on it.

Crop yields in different soil erosion status

Farmers' prediction of yield loss was based on prevalence of soil erosion indicators on the cultivated soils. Experimental assessment of the crop yield and the associated soil quality in each of the soil erosion class is shown in Table 8. Fields characterised as having high soil erosion level exhibited much lower grain yield than those fields experiencing both moderate and low soil erosion. The relative grain yield loss percentage in the eroded fields ranged from 5 to 66%. The results showed a strong agreement between farmers' crop yield loss prediction and experimental measurement in each of the erosion classes. This indicated that farmers were capable of distinguishing between different levels of soil productivity on basis of topsoil physical characteristics, which anyhow had strong implications on soil quality. Use of crop yield loss percent (yield gap percent) could therefore be a useful index to predict the soil erosion rate (e.g. high or low) and provide guidance on the remedial actions where past crop yields have shown declining trends. For instance this study showed that some farmers were experiencing a crop yield loss of up to 66 percent, which therefore meant that to attain an optimal maize yield level (3.5 ton ha^{-1}) drastic measures to improve on the overall land management was required. The widespread nature of rills, gullies and stoniness across the studied landscape attested this. These findings also pointed to the possibility that farmers ignored signs of the insidious soil erosion processes (e.g. rills and sheet), whose impact on crop yield was not as dramatic as the crop yields observed when soil erosion has attained irreversible erosion indicators (Rickson *et al*., 1987).

Table 8. Validating farmers' prediction of crop yield loss in differently eroded fields in Gikuuri catchment, Kenya.

Farmers' prediction		Measured yields‡		*Insitu* soil nutrients from 0-15cm soil depth†				
Erosion status	%Yield loss	Grain yield (ton ha^{-1})	%Yield loss	pH	Total N (%)	P (mg kg^{-1})	K (me%)	Total org.C (%)
High	50-100	1.39 (0.93)	66	4.8	0.19	20.83	0.80	1.48
Moderate	25-50	2.14 (1.36)	48	4.5	0.21	19.00	0.97	1.42
Low	0-25	3.84 (1.86)	5	5.2	0.22	34.40	1.26	1.74
Control	-	4.08 (1.73)	0	5.2	0.24	35.36	1.46	1.66

‡Numbers in parenthesis are standard deviations; †N=nitrogen, P=phosphorus, K=potassium, org. C= organic carbon.

A further evaluation of the farmers' soil erosion status and crop yield loss predictions using soil quality variables showed declining nutrient levels with loss of crop yield and soil erosion status (Table 8). Despite all soil types in the study area being acidic (refer to Table 1), the pH was much lower in fields under moderate and high erosion than in low erosion and control fields. Likewise, level of potassium (K) was much lower in fields experiencing moderate and high soil erosion, agreeing with levels found in non-productive soils by Murage *et al*. (2000) in similar soils of central highlands of Kenya. Except for total phosphorus (P) and pH levels the total nitrogen (N) and total organic carbon (C) reflected an adequate availability for crop growth thus so far not affected by the soil erosion status, a nutrient status that may be localised. Total phosphorus was more adequate (30-80 mg kg^{-1}) in low erosion class (where pH was moderately acidic) than in moderate and high erosion classes (where pH was extremely acidic). Others have found this close association between both low pH and low phosphorus levels with increasing soil loss or topsoil decline in central highlands of Kenya (Scholte, 1989; Kilewe and Mbuvi, 1990; Zöbisch *et al*, 1995). Despite weak correlation of soil nutrient levels with both the measured yields and estimated soil erosion status farmers used their knowledge to distinguish between fields that were currently unproductive as revealed through crop performance. Use of this knowledge was more common among smallholders when allocating their limited soil improvement resources on crop fields (Murage *et al*., 2000). Generally, poor correlation between soil erosion status and soil nutrient levels could be due to poor farmers' perceptions of the dynamic nature of soil fertility distribution within time and space in the sloping landscapes.

Conclusions

The study shows how farmers were more active and volunteered to present their perceptions of soil erosion impact, a problem that directly affected their means of livelihood. The study established that at transect scale the soil erosion was influenced by slope steepness more than the land use. At this scale, farmers' knowledge of erosion status strongly agreed with scientific assessment. But by extrapolating scientific erosion classes from transect to catchmnent scale a fairly moderate mismatch in erosion classes was obtained, though the disparity was more in one-class than two-class differences. Assuming a one-class difference as an acceptable error in erosion assessment by both approaches, the classification greatly improved the agreement between the two approaches. The field-by-field farmers' judgement covering the whole catchment provided a realistic scenario of soil erosion status pattern and was approved by the community as the ground truth scenario. The farmers' estimates proved realistic in identifying hillslopes that could otherwise be assumed less prone to erosion. But their realism in interpretation of erosion class associated to yield loss was further confirmed by experimental estimates. The study also showed that there was need to incorporate all attributes of the landscape in the sampled transects, when dealing with complex topographic situations and in diverse land management practices, if extrapolation to catchment or larger scale have to closely simulate the reality as farmers see it. The accuracy of scientific results could be improved by integrating some of the farmers' knowledge of their soils, especially their concept of soil erosion damage. Finally, the study suggests adoption of a crop yield loss (gap) as an index of judging level of soil erosion status, if historical crop yield data can be gathered accurately. This can however be useful evidence when discussing with farmers for the need to undertake restorative measures to attain sustainable crop production levels.

Acknowledgement

We wish to acknowledge the management of the Ecoregional Fund to Support Methodological Initiatives (formally under ISNAR) for supporting this study through the EROAHI project: The participatory and collaborative project by four institutions: Alterra, Wageningen University, KARI-Embu (Kenya) and ARI-Mlingano (Tanzania). We sincerely thank the farmers of Gikuuri catchment who enthusiastically demonstrated their great sense of the landscape diversities and current soil erosion conditions through tedious surveys and mapping processes. Support of L. Mwarasomba and J. Nyaga of MoA-NALEP (Kenya) for the coordination of meetings and the translations is acknowledged. Lastly we appreciate the roles played by the Runyenjes Township Division Chief and the two Assistant chiefs in ensuring that the study achieved its aims.

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Chapter 6

APPLICATION OF PARTICIPATORY SOIL EROSION MAPPING AND FINANCIAL ANALYSIS TOOLS IN SOIL AND WATER CONSERVATION PLANNING:

PART 1: CASE STUDY OF GIKUURI CATCHMENT, EMBU KENYA

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Submitted to: Land degradation & Development (2005)

Application of participatory soil erosion mapping and financial analysis tools in soil and water conservation planning

Part I: Case study of Gikuuri catchment in central highlands of Kenya

Abstract

Despite several approaches that aimed at mobilising farmers to embrace soil and water conservation (SWC) activities, farmers did not appreciate the campaigns since they were hardly involved in evaluation of the soil degradation. Two tools that employ farmers' participation in expressing their knowledge of mapping erosion severity and enabling them to make informed decisions in selecting SWC measures after prior awareness of net benefits of conservation measures in a series of years were developed and applied in Gikuuri catchment in Kenya. The first tool involved farmers to map soil erosion indicators and determine the soil erosion status at catchment scale, upon which they undertook to plan for SWC measures at catchment-wide scale. They also predicted crop yield losses based on the soil erosion status. The qualitative predictions were experimentally quantified to enhance understanding of the association between declines in crop yield and soil erosion situations common in the agricultural areas. The second tool demonstrated cash flow trends for a sample of farmers belonging to high, moderate and low erosion classes but also of different socio-economic and biophysical set-up. The net benefits over five years for bench terraces, *fanya juu* and grass strips and farmers' practices were illustrated to assist farmer wishing to conserve to make informed adoption decisions. The two tools increased awareness on the need for collective actions among farmers and identification of fields that are severely eroded and causing runon on downslope fields. The erosion status and financial implication caused concern and farmers' willingness to cost-share the investment costs for cut-off drains to combat sources of off-field runoff damages. Farmers widely approved the soil erosion status map since their own indicators and perceptions were used.

Keywords: *Catchment approach, Soil erosion indicators, Soil erosion class, Soil and water conservation, financial analysis, Kenya.*

Introduction

The East African highlands for a long time were recognised as the most productive agricultural areas owing to favourable soils and rainfall conditions. Because of these, population densities remained high (86-210 persons km^{-2}) but at the same time a decline in soil productivity occurred, which aggravated the living standards and environmental conditions (Ståhl, 1993; Pretty *et al*., 1995; Westerberg and Christiansson, 1999). This situation impelled the East African governments to initiate conservation strategies during the 1970s and 1980s, which among others included soil and water conservation campaigns across the country starting with the high potential regions i.e. the highlands. However, the targeted communities failed to adopt the promoted SWC measures because the top-down attitudes persisted reminding them of the colonial legacy (Lundgren, 1993).

Following these experiences, several methodological approaches were initiated and at times underwent modifications to ensure that farmers' wishes were met and all farmers participated (Pretty *et al*., 1995). The changes also aimed to stop farmer dependency syndrome there before created through provision of subsidies and financial inducements to construct the labour-intensive measures. After several modifications a new concept or strategy known as the catchment approach (CA) was conceived (Pretty *et al*., 1995; Kiara *et al*., 1999; Kizuguto and Shelukindo, 2003).

The concept of catchment approach

The CA concept is a way of concentrating resources and efforts to improve agricultural production, primarily emphasising on soil and water conservation activities, within a specified catchment area (100-500 hectares) for a limited time (1-1.5 years) (Kiara *et al.*, 1999; Kizuguto and Shelukindo, 2003). The use of the term catchment did not however imply that the target area was defined in strict sense of the hydrological drainage area but it also referred to the settlement patterns and administrative boundaries within which erosion was a problem. From the Government perspective, working in a CA was a way to overcome the problems associated with former approaches that resulted to haphazard implementation of SWC measures on individual farms. Its overall objective was to systematically and effectively conserve one area at a time, to hasten the pace of conservation and to increase production in sustainable manner with minimum damage to the environment. Through the CA it was perceived that widespread conservation coverage would be achieved when all farmers in a concentrated area were mobilised to embrace SWC practices on their own terms. The main actors in the CA were the farmers, who individually and/or collectively identified their own needs, prioritise them, mobilise the needed resources, and with technical input from extension personnel, execute the task. The CA strategy was implemented firstly by identifying the focal area to implement conservation activities, which was the responsibility of the Divisional Planning Team, made up of SWC experts in the Ministry of Agriculture in the local Division.

Secondly a participatory rural appraisal (PRA) was carried out to assess the extent of the agricultural production problems in the area. Experts from the various Government ministries took a leading role in this and at the end identified problems and actions that needed to be taken to overcome the current problems. These actions were presented to the farmers during a local public meeting where further discussions on each action were made. On basis of PRA output, the Divisional planning team drew the map of the catchment area, showing individual farm/field holdings, without the participation of the local farmers after which individual farm plans were made. These included laying out farm-by-farm SWC plans and advising the farmer the necessary measures needed to improve farm production. To convince the farmer of the viability of the farm plan, a financial farm budget was developed (Baya, 2000; Kizuguto and Shelukindo, 2003). However the farm budget did not distinguish independent benefits from each enterprise or the recommended SWC measure to the farmers. On completion of the SWC plans, the catchment committee, made up of the local farmers and one of the local extension officer were left with full responsibility to ensure that both the implementation of the laid SWC plans were constructed by individual farmers and that the farmers also adopted other recommendations related to the rest of farming enterprises, as agreed upon with the extension experts (Baya, 2000). While three to four catchments had to be implemented by the Divisional Planning Team in Kenya in 12 months, a period of eighteen months was for a single catchment area in Tanzania (Thomas *et al*., 1997; Kizuguto and Shelukindo, 2003).

In general the key features of CA in Kenya and Tanzania can be summarized as follows:

1) It's a participatory process, which involves communities in a specified area and in a specified time to ensure efficient use of resources (financial and human) for increased farm productivity.

2) It ensures all communities in the focal area are mobilised e.g. through awareness creation, training and development of common interest group action plans, to work towards achievement of uniform conservation of the farms and general environment on their own terms without government subsidies.

3) It adopts a multi-disciplinary approach to ensure sustainable management of natural resources, a process that also involves local stakeholders in decision-making, planning, implementation, monitoring and evaluation of the agreed measures. Therefore assuming a bottom-up planning approach at the catchment level.

4) Its activities are funded by the Government budget and/or donor agencies.

Earlier evaluation of the CA principles and practices by Admassie (1992) identified yawning gaps that existed and needed improvements if the envisaged CA outcomes were to be attained. Despite several methodological improvements in the functioning of CA as detailed in Pretty *et al*. (1995), Kiara *et al*.(1999) and Baya (2000), the gaps persisted and hence soil erosion problems continued in the cultivated areas of the highlands (Denga *et al*., 2000; Schneider, 2000; Ovuka, 2000).

The first gap identified was the apparent lack of satisfactory participation of the farming community in identification of soil erosion and other production problems in the catchment area. Instead the Agricultural Extension Officers led in diagnosis of the farming problems during the PRAs and public meetings, laying out SWC plans and developing of recommendations based on their experiences. This essentially undermined the perspectives of the farmers especially their knowledge of the local ecology and thus ignoring the bottom-up planning of the CA.

The second gap related to lack of bringing awareness to the farmers on the prior knowledge of the costs and benefits of soil conservation during the planning stages. Farmers were not aware of the financial benefits by implementing the recommended SWC measures in the short and long term future. Instead experts working under the CA preferred to process a financial farm budget, which showed benefits from the entire farm enterprises. Another evaluation was carried out by the project to assess the impact of CA activities 2-3 years after the commencement of SWC activities in a particular area. The catchment impact assessment was aimed at evaluating the changes in crop production, resource degradation, local resilience and vulnerability, farmers' socio-economics and whether the SWC adoption has been spontaneous within and in the neighbouring catchments.

The third and final gap identified related to CA's emphasis on individual farm-by-farm SWC planning instead of catchment scale. In this way less focus was given to public lands e.g. roads and schools, shopping centres and factories within the catchment area, and yet these were often sources of destructive overland flows.

On basis of these gaps, the new tools were developed to complement the functioning of the CA. The principle behind the new tools is that by allowing farmers to lead in the analysis of their resources, they are likely to embrace the restorative recommendations. But first they need to envision the status of their resources. This is possible through participatory mapping of the extent of the particular resource under depletion or threat, after which development of action plans could be initiated on their understanding and initiatives. Others have observed that when farmers are involved in mapping of their local conditions, there tends to be an improvement in the interaction among themselves and with development agents (Lightfoot, 1989; Gupta, 1989; Conway, 1989). At the same time as a community they enhance understanding of their common problems. Turton and Farrington (1998) observed that an approach that reflects on resource decline at catchment scale rather than farm-level had potential to catalyse widespread improvement of land-based resources and better community livelihoods. The weakness with planning one farm in isolation from the others was that runoff from one farm is likely to damage downstream farms before reaching the valley bottom areas. Currently in the CA, the farmers were not aware of each other's plans and implementation remained disjointed causing off-site damage to each other' farms.

Moreover the success of the CA can be improved when farmers become aware of the nature of the financial benefits when implementing the recommendations and when financial returns to investment can be spelt out clearly in specific time steps. Adoption of SWC measures tended to be poor because farmers hardly recognised the losses caused by soil erosion and that the recommended SWC measures were not financially attractive or otherwise farmers were not aware of it (Jones, 2002). Other reasons for low adoption was that establishment of the recommended SWC measures competed with other activities for the scarce resources, like labour, capital and equipment; and the benefits were less directly observable (Posthumus and Graaff, 2004).

In view of the identified gaps the aims of this paper were to describe two tools that were developed to complement efforts put in the implementation of the CA concept and undertake their application in Gikuuri catchment in central highlands of Kenya. Whereas this paper lays much emphasis on participatory mapping of soil erosion (the first tool)the financial analysis tool (the second tool) is only briefly described. More emphasis and on the description and application of this second tool can be found in part 2 of this series (Tenge *et al.*, 2005).

Materials and methods

The new SWC planning tools

Two tools were developed for improved SWC planning at catchment level.

The first tool, known as participatory soil erosion mapping tool, was constructed based on result of various research findings while working with the farmers' in a landscape that was experiencing soil erosion problems. The studies did identify that farmers in the highland region of Kenya were aware of the soil erosion impact which they identified using topsoil erosion features (Okoba and Graaff, 2004). How farmers estimated the extent of soil erosion was also established through another study that involved farmers in defining their indicators for classifying different soil erosion severity levels (Okoba and Sterk, 2004a). Farmers' knowledge and ability to map soil erosion indicators and on this basis estimate the soil erosion status in an area was carried out. The studies by Okoba *et al*. (2004) and Okoba and Sterk (2004b) established that farmers clearly associated certain crop yield levels to specific soil erosion indicators and levels of soil erosion status.

The second tool referred to as financial analysis tool, according to Tenge *et al*. (2005), undertakes to analyse the investment and production costs, in time, for different SWC options for farmers in specific socio-economic and biophysical characteristics. The input parameters for this tool required knowledge of soil erosion status according to the participatory soil erosion mapping tool, the costs of constructing and maintaining all known SWC measures by farmers and knowledge of the prevailing labour costs and farm product prices (Tenge *et al*., 2004). Therefore the tool enabled farmers to make investment decisions with prior knowledge of the costs and benefits with time on the selected SWC measures but also comparing this to the current income from a situation without SWC measures.

Description of the participatory soil erosion mapping tool

The tool consists of six steps (Fig. 1), which are briefly described hereafter. It is assumed that a catchment or focal area for SWC activities has already been selected.

Step 1: The identification of key informants from the local farmers is of vital importance because of their familiarity with the local environment they will lead the rest of the community in the subsequent steps in the tool. They should be full time farmers and drawn from spatially well-distributed households within their respective villages.

Output step 1: List of catchment key informants or village representatives.

Step 2: A public meeting is held since it will allow the community to assess the activities and factors that concern the water erosion processes in their local environment through a focussed PRA on aspects of land degradation and environmental issues. Based on the understanding of the on-going soil erosion processes, type of indicators the farmers associate with soil erosion events that took place recently or in the past can then be analysed. Thereby generating a list of soil erosion indicators. With this list the identified key informant will make a familiarization transect walk across their individual villages to verify and add to the list any other erosion indicators not mentioned during the public meeting. After the transect walks another public meeting could be held to present to the community the whole range of erosion indicators after the transect walk by the key informants. During this meeting an in-depth analysis of the listed indicators is recommended. Specifically compiling what would now be referred to as the consensus list of erosion indicators. Also all participants could confirm whether they consider each of the compiled erosion indicators as typical consequence of soil erosion processes. It’s important that the indicators are clearly discerned to avoid confusing symptoms or factors of soil erosion for erosion indicators. Farmers can also distinguish between indicators that have developed due to current erosion events and past erosion events. During the same meeting, ranking of indicators with respect to their relative importance to soil damage can be assessed using pair wise analysis. Farmers will discuss and justify to each other why they think a certain indicator should be considered to represent either higher or lower soil loss status than others.

Output step 2: Consensus list of soil erosion indicators distinguished between current and past indicators and the relative severity rankings based on farmers' perception.

Step 3: The key informants take lead in drawing of the catchment map during a public meeting. This map should show all the individual fields and the infrastructures in the area. This step gives the farmers an opportunity to know other farmers beyond their villages or identifying who owns which field. Though the key informants undertake the identification of field arrangements and shows on the map, in accordance to the ground situation, the rest of the community ensures that fields are laid out correctly and the field owners are identified accordingly. The catchment map can be drawn on the ground or on an appropriate surface. The experts or the key informants can then copy the map on the ground to a sheet of paper for the next step

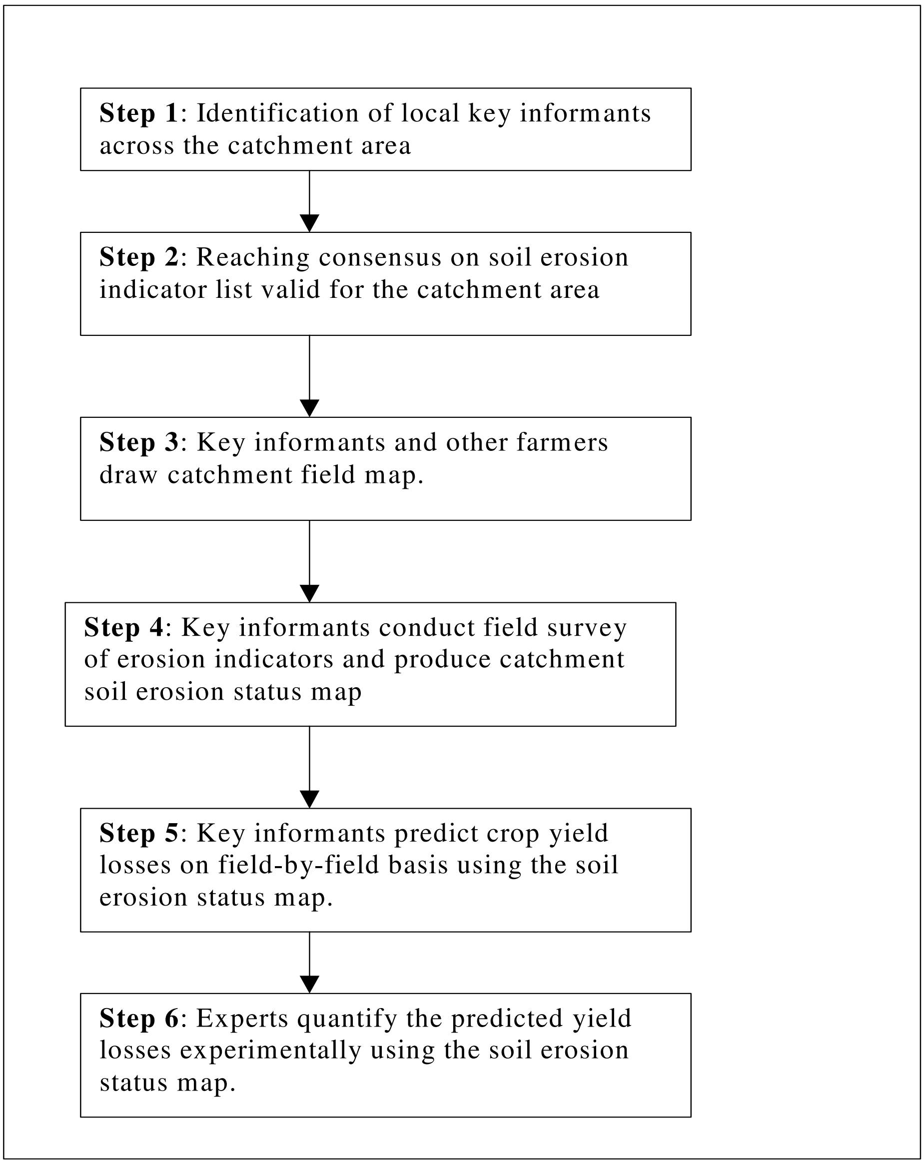

Figure 1. Schematic steps in the tool for soil erosion mapping and quantification using farmers' knowledge of soil erosion indicators

Output step 3: Catchment field map.

Step 4: Using the catchment field map, the key informants can undertake field-by-field survey of erosion indicators evident on every field shown on the catchment field map. During this survey the key informants record all the erosion indicators present in a particular field and showing (if necessary) where field segments are prone to specific types of erosion indicators. While in the field the key informants can unanimously estimate the soil erosion status on the basis of the degree and multiplicity of the erosion indicators exhibited on each field segment. The determined soil erosion status on the field need to be reflected on the field map too, showing field segment boundaries as accurately as possible. The farmers in the area could verify how accurate the erosion severity was estimated. It is advised to carry out the survey at the end of a rainy season and when the field-crops have achieved physiological maturity but before farmers start harvesting, an operation which destroys evidence of topsoil erosion indicators.

Output step 4: Catchment soil erosion status class map.

Step 5: Once indicator survey results have been aggregated over the whole catchment and the soil erosion pattern or status map clearly labelled, the key informants need also to determine the effect of the erosion status has on current season's crop yields. This is better assessed by the key informants' visit to all the fields and based on the erosion status, as previously judged, they then predict the crop yield levels. These levels can be described as possible percentage yield loss at the harvest time the farmer was likely to loose because of the current soil erosion status in a given field.

Output: Table showing linkage between soil erosion class and estimates of crop yield loss.

Step 6: The experts quantify farmers' qualitative crop yield loss predictions. Using the soil erosion map samples of fields under different soil erosion status can be selected and during a cropping season, the crop yields can be assessed. During this data collection, the crop type should be the same in all the sampled fields. Information on crop yields levels from a reference (control) soil within the catchment area is necessary especially for determination of the actual crop yield loss in different erosion status classes. This is calculated by getting the crop yield difference between yields obtained in reference soil and the yields from fields under each of the soil erosion status classes.

Output step 5: Experimental results of estimated crop yield levels and percentage losses in different soil erosion classes.

An extra step to step 6: As a conclusion to the erosion and crop yield scenarios, a village meeting could be organised to seek from the farmers which SWC measures and management strategies they would implement to bring the desired changes.

Description of the financial analysis tool (short version)

The financial tool is based on assumption that the costs and benefits of SWC measures vary among farmers and across different physical and socio-economic situations. Therefore the starting point to involve farmers in identifying and costing the various SWC options is to identify the current status of soil erosion and level of crop yield loss he/she is experiencing: based on the final step of participatory soil erosion mapping tool. This is because farmers experiencing different soil erosion effect will be identified but also the public lands that are sources of runoff and cause damage to downstream fields will similarly be identified. The financial tool establishes the costs and benefits of the SWC measures by comparing the streams of benefits and costs in time. The following is the brief description. Important steps are hereby shown but details can be found in the second part of this paper series (Tenge *et al.,* 2005).

1) Establish the fields' location on the catchment erosion map derived by the participatory soil erosion mapping tool. Other field characteristics can then be determined, e.g. slope, soil type, farm size etc. Also find the farmers' socio-economic class by knowing his/her opportunity costs of labour, current crop yield level etc.

2) Identify, quantify and value all costs in construction, production of the current state (without SWC) and maintenance if SWC measures are implemented.

3) Identify, quantify and value all benefits expected from implementing SWC measures.

4) Determine net benefits and cash flow in time: comparing benefits from with and without SWC situations and consider the revenue for a number of years (cash flow) from which trends in the cash return to investment can be seen.

5) Discounting to the present situation i.e. expressing the future benefit to the present situation (cash flow at a desired time multiply by the discount factor).

6) Discuss with the farmers on the scenarios: Results are discussed with the farmers until a financially feasible option is identified.

Output: Costs and benefits for the selected SWC measures over time for each farmer

Location of the study area

The tools described in this paper were developed and applied in Gikuuri catchment, a site that represents the humid climatic conditions found in the highlands of East Africa. The catchment is located on the lower footridges of Mt. Kenya at 00^0 26´S, 37^0 33´E and at an elevation range of 1302-1500 m in Embu District in the Eastern Province of Kenya. The catchment has an area of about 5 km^2 and a population of about 657 households. The percapita land size is between 0.25-3.00 ha and most farmers own titles to their land. Halve to three-quarters of land is devoted to mainly coffee growing whereas the rest is allocated to mixed cropping systems that consist of maize, beans, bananas and potatoes. Agroforestry is practiced across the study area, which is dominated by inclusion of macadamia, mangoes and Gravellea robusta tree systems within food crop fields. Dairy cattle and goats are kept on a zero grazing system due to small land sizes. The rainfall is reliable throughout the year and comes in bimodal regimes (March-May and October–December). Besides adequate annual rainfall (1270 mm) for arable agriculture, the soils are well drained and deep (>1.6 m). However, due to topsoil removal by soil erosion the soil fertility levels have declined variedly across the landscape positions. Thus restoration of soil nutrients and conservation of the soils against erosion has been pointed out as a prerequisite for optimal agricultural production (Wanjogu, 2001). Past efforts to coerce farmers to adopt SWC measures and ensure sustainable production on their small land parcels were not widely successful, as demonstrated by the current level of SWC measures implemented across the landscape. Few and widely spaced strips of SWC measures can be observed on the steeply sloping (12-55%) hillslopes. Fanya juu, cut-off-drains, bench terraces, grass strips and blocks of Napier grass are the common types of conservation structures seen on the farms but long-time negligence to maintenance is apparent.

Application of the tools

Participatory soil erosion mapping tool

The participatory soil erosion mapping tool was applied in the study area at different stages between 2001 and 2003. The expert interested in application of this tool could be a research scientist who would then be required to guide the community of farmers in the process of applying this tool. In this paper, the authors undertook to apply this tool with the key informant farmers playing a major role of facilitating the process. However, whereas all the steps in the tool reflected farmer-led participation to prove their knowledge of the local ecology, initially the Agricultural Extension officers and the local Government administrators assisted with introducing us (research scientist) to the study area and the community at large and the local village leaders. The Agricultural extension officers showed the extent of study area, where also previous CA activities had failed to convince farmers to see the need of implementing SWC measures. The local village leaders identified few farmers who took up the role of being our key informants (step 1). These facilitated in conducting of a focused PRA activities on specific issues of land degradation and changes farmers had observed to the physical environment. The PRA was carried out within a period of one week in December 2001. The PRA methods were used to analyse the production problems and identified the prevalent erosion indicators (step 2), which were then ranked according to their severity damage to the soil. A farmers' meeting was organised and together with the key informants a map of the study area was defined (step 3).

The key informants surveyed the extent of soil erosion indicators in the area during the dry period after the October-December 2001 rainfall season. Based on the knowledge of the soil erosion indicators and field map of the study area the key informants carried out erosion mapping throughout the catchment area during the rainfall season of March-May 2002 and October-December 2002 (step 4). The community was later presented with the catchment-wide soil erosion status map, drawn on a large clothe, and asked to approve the soil erosion status specifically the class(es) assigned to their individual fields (step 4). To further gain more insight on what the farmer perceives of the erosion status the key informants could be asked to estimate the likely crop yield loss the farmer was likely to suffer due to the soil erosion status levels (step 5). Researchers then experimentally evaluated the crop yield levels associated to each of the soil erosion status class, shown on the map, during the March - May 2003 rainfall season (step 6).

Because of the threat of soil erosion on crop production, we sought to know from the farmers during a public meeting the best-bet SWC options for fields experiencing soil erosion. Also for the public areas we enquired for lasting solution to curb the overland flow damage, emanating from these surfaces, to the downstream fields or infrastructures. By reflecting on catchment-wide soil erosion situation and allowing farmers to suggest SWC option, we however hoped that collective action towards implementation of SWC measures would be realised at a catchment scale.

Financial analysis tool

This tool was applied to a sample of farmers to illustrate the importance of *exante* financial analysis of investing in SWC measures. During the months of October through to December 2003, input parameters for this tool were collected from 60 farmers whose fields were experiencing different soil erosion problems. From each of the three soil erosion class, 20 field holdings were identified and data for the tool was gathered through farm visits. During the visit the farmers' socio-economic characteristics and wishes with respect to preferred crops and SWC options were established. After considering all costs and benefits the cash flow with time, of five years, for individual farmer was produced and discussed to identify the farmer's preferred choice of SWC measures for adoption.

To illustrate the results of this tool in this paper a sample of six farmers, two from each erosion class, were selected to represent the different socio-economic and biophysical settings. This sample shall demonstrate the importance of farmers making informed decision after seeing the financial potential when SWC measures are implemented. These farmers were selected because they were from a single hillslope showing inter-farm connectivity hence effect of on- and off-site interactions were clearly illustrated in terms of extra costs a farmer in downstream areas has to incur due to runon. Their social and biophysical characteristics are shown in Table 1.

Table 1. Characteristics of the selected farmers in Gikuuri catchment, Kenya

Variables	Sample farmers					
	F1	F2	F3	F7	F8	F9
Labour opportunity costs (US$/day)	1	1	1	1	1	1
Field area under consideration (ha)	0.4	0.8	0.6	0.6	0.2	0.6
Field slope gradient (%)	30	20	25	20	20	15
Erosion class (from the farmers' map)	High	Moderate	Moderate	Low	High	Low
Does the field receive runon? (Y/N)	Yes	Yes	Yes	No	Yes	No
Current crop yields (100*kg ha^{-1})						
Maize	14.8	19.6	15	20	14	16
Beans	3	2.4	2.4	2.1	3.5	2.1

Results and discussion

Identification of key informants (step 1)

In the study area, local village leaders identified 28 key informants, composed of 19 male and 9 female, to provide a facilitators' role in applying the soil erosion mapping tool in the seven villages of the Gikuuri catchment. It was not possible to find a balanced gender distribution as most of the suggested female key informants when approached to be part of the key informant team declined the offer due to the busy household chores. Even with the few females who volunteered to participate, they ensured that the team activities had to be prior planned and executed timely. Generally the key informants' activities were executed during off-peak farm operation periods.

Consensus list of soil erosion indicators and their relative ranking (step 2)

The motivation for the catchment farmers to establish the impact of soil erosion on their soils was demonstrated by their collective commitment to illustrate their knowledge of soil erosion indicators and the relative severity ranking of these indicators (Table 2 and Fig. 2). During the public meetings, it was observed that when experts take back seats and let the farmers take charge, the final decision represented a consensus agreement. This was because the knowledge of soil erosion processes and consensus list of topsoil erosion indicators represented views of farmers. For instance the process of achieving a consensus on the ranking of erosion indicators tended to raise a lot of arguments among farmers, sometimes requiring that farmers make their views clearer by visiting typically eroded hillslopes. Final resolutions on relative severity of the widespread soil erosion indicators showed that presence of gullies, broken SWC structures and stoniness on soil surface indicated that erosion situation was not desirable and a condition of such soils were perceived to be in danger as far as crop production was concerned. But when soil surface exhibited indicators such as splash pedestal, sheetwash and soil texture starting to become loose, the erosion was perceived as low. Therefore the order of ranking reflected the degree of soil damage a particular or combinations of indicator(s) represented when observed on the soil surface. Farmers also distinguished between the erosion indicators that had evolved because of current or past soil erosion events. This helped them to understand the history of soil erosion in a particular field and therefore judge whether currently exhibited soil erosion situation was high, moderate or low. Many farmers were able to reflect on their own fields and state when they started seeing the changes in topsoil characteristics. A phenomenon they closely linked to declining soil productivity. They observed that past erosion indicators were indicative of dramatic decline or failure of crop production.

Figure 2: Pairwise analysis of soil erosion indicators and ranking by farmers of Gikuuri catchment, Embu, Kenya.

Table 2. Consensus list of erosion indicators and relative severity weight ratio rankings by Gikuuri catchment farmers, Kenya

Indicators	Total frequency count	Weight ratio	Severity Ranking order*	Current (C) or past (P) indicator
Gullies	11	0.17	1	P
Broken SWC measures	10	0.15	2	C
Stoniness	9	0.14	3	P
Red soil colour	8	0.12	4	P
Rock exposure	7	0.11	5	P
Rills	6	0.09	6	C
Root exposure	5	0.08	7	C/P
Sedimentation	4	0.06	8	C
Sheetwash	3	0.05	9	C
Splash pedestals	2	0.03	10	C
Loose soil	1	0.02	11	P
	$\sum$=66			

*Where severity ranking of 1= high erosion and 11=low erosion.

Farmers' reaction: Drawing catchment map and the soil erosion status (steps 3 and 4)

The key informants together with the catchment farmers demonstrated their knowledge of the local physical environment by sketching out a catchment map and showing all individual field holdings (Fig. 3). The key informants' field-by-field survey resulted in field delineations according to severity of soil erosion status (Fig. 4). The identification of high or low erosion classes was based on farmers' knowledge of soil erosion indicators as shown earlier in Table 2. Aggregating all the soil erosion status field patterns resulted into the catchment-wide soil erosion map indicating the erosion patterns for different field units (Fig. 5). The map illustrated distribution, extent and connectivity of soil erosion classes in different field holdings. Erosion classes were in three categories: high, moderate and low, according to farmers' perceptions. On a hillslope scale, fields experiencing high erosion tended to be on the mid or at the bottom of the hillslope, whereas fields experiencing moderate or low erosion were located in the upslope areas. Implying that either the upslope fields could be source areas for overland flow therefore negatively affecting downstream fields or due to steep slopes the downstream fields were more susceptible to soil erosion impact. Farmers tended to notice combinations of gullies, stoniness, rock outcrops and red colour topsoils along the steep slopes in the downstream areas thus classifying the erosion status as high.

In order to verify whether the villagers were in agreement with the key informants representation of the soil erosion scenario, village-by-village display of the map resulted into significant reactions. Whereas there was a consensus agreement to the depicted erosion pattern some farmers contested the outcome of the erosion classes assigned to their individual fields. In such cases the key informants either readjusted the status, accepting the misrepresentation or justified their judgement by consulting their field notebook to re-check the types and extent of erosion indicators observed during the field survey. The interest to check erosion classification indicated that community was keen to confirm the outcome of the key informants' appraisal of the soil erosion status.

However farmers observed that the soil erosion map at the catchment scale, showing individual field situation, greatly improved their scope of understanding the extent and degree of soil erosion as a community. It was also an opportunity for them to reflect on the soil degradation status and thus motivating them to forge better land management practices either on individual or collective basis, as the situation may demand. One female farmer asked to react to the erosion scenario, she remarked this way:

"*Though I have lived in this location for the last 30 years I did not know that most of our farms were so badly eroded and I think as a community we need to conserve our land otherwise we are all perishing. I appeal to those whose farms are sources of overland flow to care about us in the downstream as our efforts may just be put to waste in one season or storm*".

Figure 3. Gikuuri farmers drawing catchment map showing all the field holdings.

Some villagers observed that they could now understand why their formerly fertile fields lying in the valley bottoms, despite plenty of water, the crop production had drastically declined. Others expressing despair observed that at the current rate of soil erosion scenario, there was no longer any need to invest their dear resources in fields located in the valley bottoms, as "poor" soils containing sandy and stony/gravels materials continued to pile over the fertile soils. Implying that unless upslope farmers cared the erosion scenario might worsen in the near future.

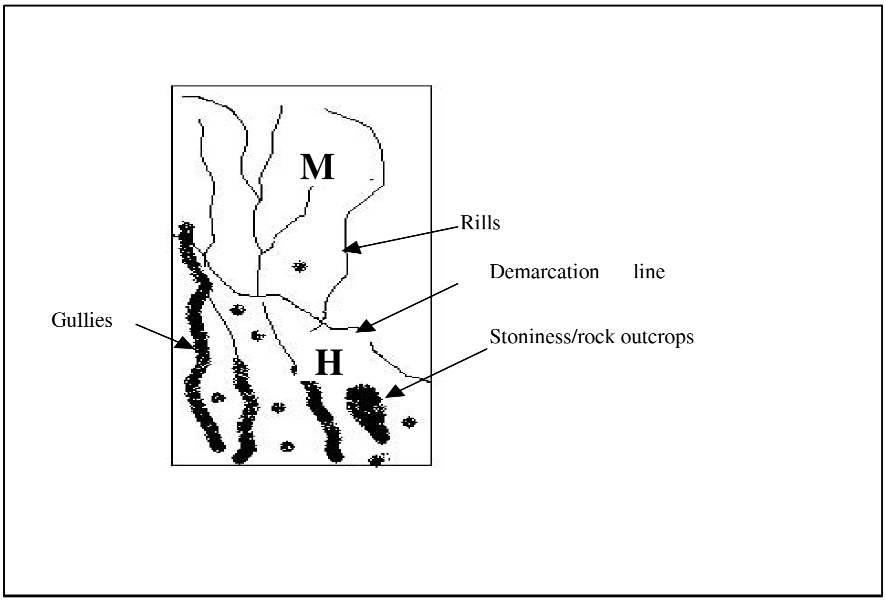

Figure 4: Example of non-uniform spatial extent of erosion indicators and the soil erosion status classes (H=high and M=moderate) as estimated by farmers based on the onsite assessment of soil damage.

Range of crop yield loss per erosion class, SWC plans and collective actions (steps 5 and 6)

Other studies have observed how soil and water dynamics were functionally related to vegetation patterns on hillslopes (Imeson and Prinsen, 2004). In this study soil erosion classification was perceived by farmers to be closely associated to crop yield losses. Key informants' checks in the field tended to relate fields experiencing high crop yield losses with where severe erosion indicators thus high erosion status was located. Despite the differences in soil types and topographic positions key informants data showed that the topsoil erosion features were perceived to be the same and affected crop production equally. Estimated crop yield loss in the valley bottom areas and on the steep mid slopes hardly differed given that valley bottom area were overlaid by soil materials from the upslope topsoils, which were severely eroded. To quantify the farmers' prediction, field experiments established threshold crop yields for each erosion class (Table 3). The results indicated how close to reality farmers' predictions were to actual crop yield levels. Farmers' perceptions that low erosion fields stood to lose less than 25 percent and those in high erosion fields would lose between 50-100 percent was proved through field experiments that established ranges of yield loss values matching the farmers' predictions. Despite these, the yield levels in fields experiencing high and moderate soil erosion levels, accounting for 69% of the area, are below the recommended optimal maize crop yield levels in the region, of at least 3.5 ton ha^{-1}.

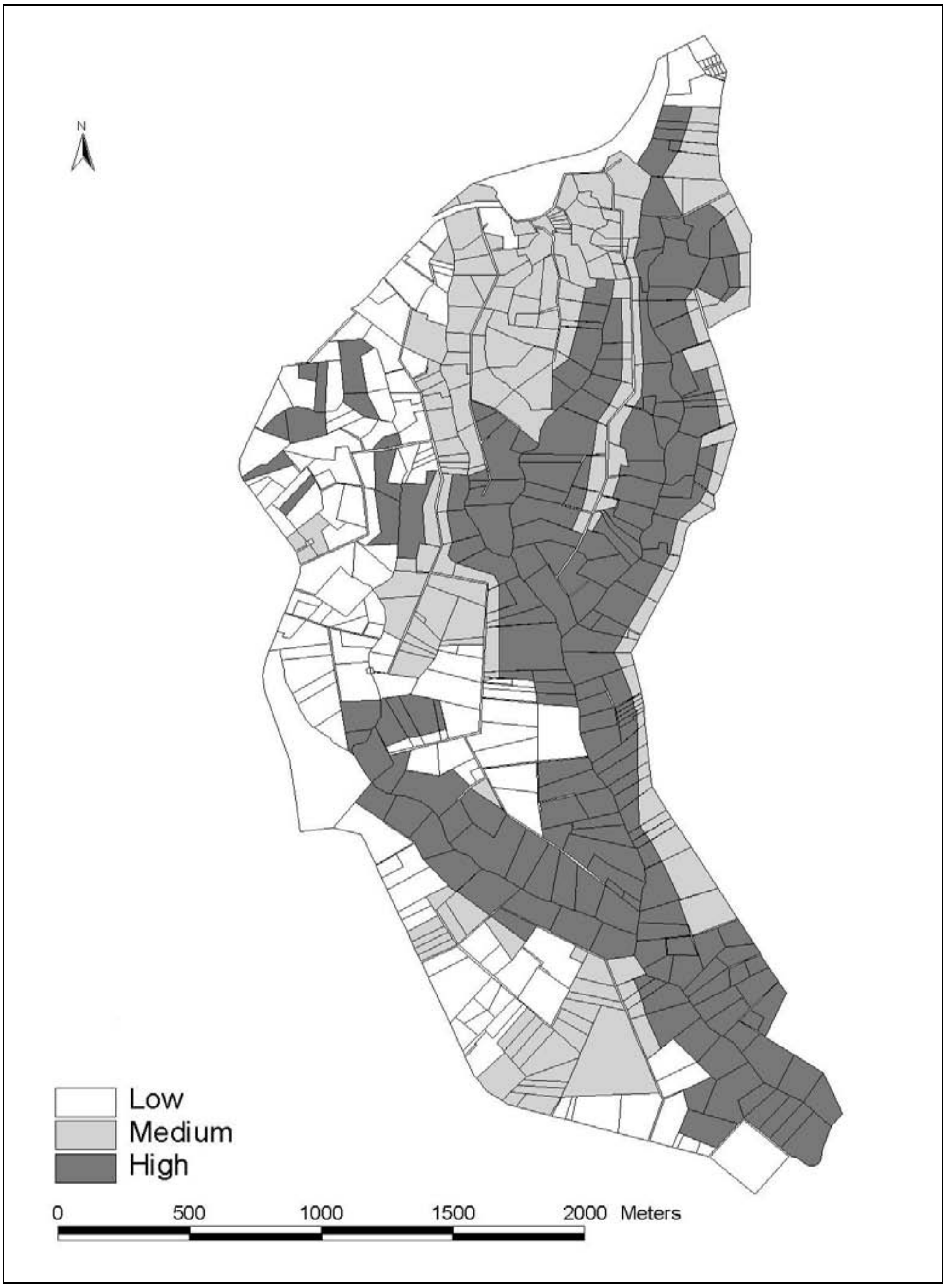

Figure 5. Gikuuri catchment soil erosion status map according to farmers' views based on distribution and extent of soil erosion indicators in each field holdings.

These findings however point at the importance of farmers seeking for ways to counteract the ongoing soil erosion and restoration of lost soil fertility. Vanclays, 1997) observed that where farmers experienced a severe form of land degradation, they were likely to feel powerless in address the problems, instead of undertaking reclamation actions or fundamentally change their management practices. The farmers in the study area did not seem to have better option to overcome the extremely eroded hillslopes but to abandon and seek alternative fields elsewhere for cultivation on contract agreements.

Table 3. Mean grain yields and percentage grain yield loss of different soil erosion classes.

Erosion status class	Farmers' predicted crop yield loss (%)	Measured mean crop yield[†] (t ha^{-1})	Measured yield loss range (%)
High	50-100	1.39 (0.93)	70-80
Moderate	25-50	2.14 (1.36)	40-67
Low	<25	3.84 (1.86)	2-16
Control[‡]	-	4.08 (1.73)	0

[‡]This is reference soil where erosion is perceived to have had minimum effects;
[†]Values in parenthesis are standard deviation from the mean.

After a lengthy brainstorming sessions and reflecting at the catchment-wide soil erosion status map, farmers reached a consensus and recommended specific SWC measures for different soil erosion classes, slope categories and public areas (Table 4). Whether individual farmers followed the recommendations it would depend on the potential benefits a particular measure was capable of meeting the farmers' needs e.g. financial income and crop production sustainability. Despite the severe catchment-wide soil erosion scenario, the farmers did not indicate the possibilities of undertaking the conservation activities collectively as a community. It was widely observed that due to bad experiences of group work in SWC activities it was not efficient to construct the measures in a group framework at a catchment scale. Mainly because some community member tended to use such chances to "free ride" on the efforts of others and some abandoned group work after their fields had been conserved. Therefore resulting into poor relationships and lack of trust in communal activities. However they observed that the only opportunity to undertake conservation as a group or family was between neighbouring farmers where each one of them realised the extent of overland flow damage from one field to adjacent fields. Otherwise communal activities were still possible on public areas where law enforcement was still operational: such as school compounds - for parents, village roads – for villagers and compounds of coffee factories – for members of the particular coffee cooperative society.

Assumption that farmers were likely to adopt environmental management techniques as a community when they consider themselves at risk from the environmental degradation (Rickson *et al.*, 1987; Vanclay, 1997) did not generally result in communal thinking or mobilisation that would yield to attainment of uniform conservation. Though the level of concern for the damage caused by inter-farm overland flow was now a more sensitised issue than before, after reflecting on the pattern of soil erosion status, communal enforcement was still remote to attain. Communal efforts in the study area were observed to be more likely successful with regard to water supply projects, where farmers participated in purchase of conveyance pipes, digging of trenches and even ensuring that water flow was sustained.

Table 4. Typical SWC measures farmers recommended for each erosion class and for various types of public lands in Gikuuri catchment, Kenya.

Soil erosion class	Slope steepness condition and public area types	Type of SWC measures suggested†
Low	Flat-gentle	GS, R&F+mulching , Hedgerows
Moderate	Gentle	GS, hedgerows, FJ+GS
	Steep-very steep	FJ+GS, GS
High	Steep-very steep	FJ+GS, BT, BT+GS, FJ+R&F, vegetated COD
Public lands	Within village roads	Good drainage, grading/levelling, fill pot-holes
	Institutions (coffee factory, schools, churches etc)	COD, levelling, lawn grass, broad level BT

†GS=grass strips, FJ=*Fanya juu*, BT=Bench terraces, COD=Cut-off-drains, R&F=Ridge and furrow.

Illustrating cash flow analysis

Based on the socio-economic and biophysical setting of the sampled farmers, the cash flow analysis using a set of three SWC measures as the possible options for adoption was illustrated (Table 5) to the six farmers (refer to Table 1). The financial analysis here does not show much details on input data and procedures of costs-benefits analysis, as this is done in Tenge *et al*.(2005). The three SWC measures were used because they were the most mentioned by the community during the catchment-wide SWC planning, and most recommended by Extensionists in the region. It was important to show the costs and benefits likely to be experienced when farmers from different socio-economic setting adopted these three measures. The cash flow for each of the six farmers was one way of comparing the currently earned benefits with what they could earn if they considered adopting alternative land management options. In all the cash flow scenarios, the year-zero represented the investment cost at the implementation of conservation measures before considering the returns. The investment cost was only of effect initially and did not account on the cash flow in the subsequent years. The year-one is the year after conservation and when production of the farm was being considered. Negative cash flow values meant that the costs of production were higher than the benefits accrued after investing in crop production alone (for the case of without SWC situation) or after investing in both SWC and crop production.

The cash flow in the without SWC situation (i.e. current), showed that all the farmers were operating at a loss (negative benefits) except two whose cash flow were positive though likely to declining in the longer term due to continuing loss of soil fertility through surface runoff. Considering the with SWC situation, the year-zero cash flow tended to be extremely higher than the current benefits each farmers was getting in the without SWC situation, justifying how it was hard for farmers to effectively invest in SWC activities. This was the case when considering income gained after sale of cropped maize and beans, and fodder grasses planted along the slope contour on the land or equivalent value of milk and farmyard manure from the dairy cattle. Though farmers in the study area grow other infield crops besides maize and beans, like coffee, we chose to consider maize and beans crops. These two crops were perceived to be commonly grown and most sensitivity to soil and water loss which SWC measures and other fertilizing methods could improve their production hence farm cash income. At the time of the study farmers had despaired on depending on coffee cash income due to poor market prices. The illustration also showed that by experiencing runon from upslope areas, all farmers except two (F7 and F9) had to incur extra costs of constructing the cut-off-drains to protect the desired SWC measures from damage (see values in parenthesis during year-zero – Table 5). The analysis showed that by adopting bench terraces or *fanya juu* and stabilized with grass strip the costs in the first year outweighed the benefits (negative values) for all the farmers. Though we cannot compare one farmer with the other, the investment costs (year-zero) were relatively much less by adopting grass strips than adopting the other two SWC measures. Because in the without SWC measures situations, farmers F2 and F7 were experiencing high crop yields and financially profitable such that they could still start realising a positive return by adopting grass strips by the first year.

When we discussed with each farmer the financial outcome based on their socio-economic and biophysical set ups, each of them preferred to start with grass strips and probably supplement it with less expensive conservation tillage practices like ridge and furrows and tilling along the contour instead of the currently practised up-down slope tillage direction. They perceived that when the farm financial income improves, after adopting the grass strips measures, then they would construct more lasting measures such as bench and *fanya juu* terraces. There was a wide appreciation of introducing financial implications prior to undertaking conservation activities. It was observed that due to lack of such knowledge many farmers started on conservation ventures that they could not realise the benefits within their time horizons leading to abandonment and incomplete constructions across the farm. They also felt that the burden of bearing investment cost (year-zero) alone could be reduced through sharing with the farmers on the upslope areas and who were identified to be responsible for runon. Farmers suggested that it would be socially encouraging if farmers who were not able to install the infield SWC measures started by constructing graded cut-off-drains to avoid further off-site runoff damage on their neighbours' fields.

This analysis highlighted the importance of providing a quantitative financial valuation of proposed SWC measures before farmers carry out implementation. It also shows the importance of farmers recognising that they had to incur costs that they could avoid had the upslope farmers undertaken conservation, thus avoiding off-site effect to downslope areas. It does emphasis the need to plan SWC measures at a more than individual farm scale, probably at least at a hillslope scale so that farmers could negotiate on how to share costs of investment on some conservation structures. In general, the application of the participatory soil erosion mapping tool does highlight some important ingredients of a participatory activity that are most often under-estimated in the implementation of SWC activities in the current CA. Use of farmers' knowledge of soil erosion indicators enhanced overall community motivation to participate in soil erosion assessment. Awareness of soil erosion severity was more widespread among the community members after reflecting on the catchment-wide soil erosion scenario and discussing its impact on crop production. An opportunity that is hardly available in the current steps of the CA activities. The tool improved collective brainstorming sessions resulting in suggestions to develop best measures to combat soil erosion and identification of sources of surface overland flows. It also enhanced solidarity and familiarity between neighbouring farmers experiencing similar problems.

Table 5. Cash flow trends (up to 5 years) for selected farmers showing their current, considering three different SWC options in Gikuuri catchment, Kenya.

		*Cash flow (US$) among the different SWC options											
		BT+GS				FJ+GS				GS			
Farmer	Current‡	Year 0†	Year 1	Year 3	Year 5	Year 0	Year 1	Year 3	Year 5	Year 0	Year 1	Year 3	Year 5
F1	-3	181 (13)	-39	28	63	162 (12)	-28	16	36	99 (12)	-16	8	28
F2	22	262 (17)	-83	109	132	240 (18)	-72	49	72	156 (18)	19	31	54
F3	-10	229 (15)	-51	85	104	208(15)	-40	41	62	130 (16)	-27	30	50
F7	23	189 (0)	-49	90	111	172 (0)	-35	59	81	109 (0)	12	15	22
F8	-9	87 (9)	-12	23	42	81 (9)	-11	23	42	60 (9)	-9	20	22
F9	-10	164 (0)	-47	94	115	152 (0)	-37	84	104	104 (0)	-25	53	54

‡Reflects cash flow without SWC measures; * This considers the income from sale of maize, beans and fodder grass: BT=bench terraces, FJ=Fanya juu, GS=grass strip; † year-zero implies investment cost at implementation, while the values in the parenthesis are the extra investment cost the farmer must incur because of runon from upslope areas.

These observations could complement some steps in the current CA's SWC activities e.g. mapping of catchment area, problem identification, SWC planning and development of action plans stages. This would remarkably make farmers own the problems at individual and catchment scales and improve success of SWC activities as described in the CA strategy.

Conclusions

The use of the two participatory tools discussed above shows how farmers apply their knowledge of the local ecology to bring widespread awareness of the soil erosion indicators and status of the soil erosion to the community. The tools helped building of common views by the community on the impact of soil erosion on soil productivity, also assisted farmers to be able to identify fields or hillslopes that were suffering from severe soil erosion problems. The study does demonstrate that when farmers conduct their own evaluation of soil degradation they readily accept the depicted erosion scenario as their own than when an outsider conducts the same evaluation. Apparent outcome of the soil erosion mapping tool was that sources of surface runoff that damaged downslope fields could be identified leading to collective planning of SWC measures at catchment scale. Farmers distinguished between SWC plans suitable for individual farms and those for public lands. Collective implementation of conservation measures was only perceived practical and socially feasible at hillslope scale rather than catchment scale for infield conservation activities.

The financial analysis demonstrated how farmers could make informed decisions when they are aware of their current and future financial position in with and without SWC situations. Application of the financial tool demonstrated how a farmer planning to conserve could resolve for financially suitable SWC measures that fits his/her socio-economic and biophysical setting therefore overriding blanket recommendation from the experts. The stepwise analysis of costs assisted farmers to identify conservation structures that must be undertaken collectively e.g. public properties at catchment scale and at hillslope scale for construction of structures like cut-off-drains, to counter overland flow between farms. It also points at the need for farmers who may not afford to construct their infield conservation measures to start by constructing cut-off-drains structures to avoid causing their neighbours from incurring costs that could be avoided.

Therefore adoption of these tools could add value to SWC projects in many ways. Firstly, it could increase acceptance of expert-generated recommendations after gaining insight in the farmers' self-evaluations of problems and solutions. This is so because farmers tend to be sceptical of extension messages and they are only accepted after they have been evaluated by individual farmers' knowledge and beliefs. Secondly, the project resources could initially target areas the farmers identify as the "hot-spots" of soil erosion problems and thereafter focus on next less degraded areas in a catchment area.

Acknowledgement

We wish to acknowledge the financial support from the Fund for Methodological Support to Ecoregional Programmes (The Netherlands) and the KARI Director for logistic support during the research period (2000-2004). The Gikuuri catchment community: The farmers, Ministry of Agriculture Extension Officers and local leaders are highly appreciated for their support throughout the period we worked together in the area.

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Chapter 7

SUMMARY AND CONCLUSIONS

Summary and Conclusions

Environmental degradation in the humid central highlands of Kenya is widespread and has a long history that stretches far back to the colonial times. Steep slopes, high rainfall intensities and population pressure are some of the factors that make the fragile highlands be susceptible to environmental degradation. Moreover because of suitable agricultural conditions land pressure continues to be a major bottleneck to every effort to enhance food production to meet the population demands. One way to address the environmental degradation was through enforcing construction of soil and water conservation measures.

Whereas several approaches have been tried to make farmers install conservation measures in the country, the targeted small-scale farmers have failed to adopt conservation measures. During the colonial times use of force did not succeed nor after independence did the many tried approaches reduce the declining soil productivity. Use of tangible incentives did not prove sustainable, nor was the use of individual farmer approach led to disjointed implementation of conservation measures. Consequently an approach known as Catchment Approach was formulated. This aimed to mobilise farmers in a focal area and ensure that all farms in the area were conserved leading to a uniform conservation in a period of one year.

Despite various modifications in its methodological approaches the Catchment Approach concept did not realise its objectives. Particular gaps hindering it to realise the envisaged objectives were to do with lack of involving farmers to fully participate in understanding the problems hindering improved land production. As such farmers' knowledge was undermined in all the stages of the Catchment Approach. The experts implementing the approach largely relied on their experience in aspects of soil erosion assessment. Farmers were perceived ignorant and the recommendations were issued with less regard to making the farmers know the financial impact with time. The approach failed to work with community at catchment scale with regard to soil and water conservation planning preferring to plan at individual farm scale. Therefore a methodological project aiming to develop simple participatory tools to improve the Catchment Approach was initiated and sited its activities in the highlands of East Africa. This thesis reports on activities of a sub-project that was located in a representative humid highlands region on footslopes of Mt. Kenya at Gikuuri catchment in Embu District, Kenya.

To obtain insight on farmers' knowledge and perceptions of the widespread soil erosion problems, a survey was carried out to gain awareness of soil and water conservation measures, and the possible constraints to widespread adoption of these measures. Through focussed community group discussions and household interviews of 120 farmers, equally distributed among the three land management classes that were distinguished by key informants' criteria, the farmers' perceptions were gathered. Largely it was found that farmer were not ignorant of the on-going soil erosion damage. The 98 percent of the 120 farmers interviewed, confirmed that they were experiencing soil erosion phenomenon which they affirmed by listing the erosion indicators widespread on the fields. They attributed the formation of these indicators to soil erosion triggering conditions that were beyond their control. They stated that high rainfall, runoff from upslope fields, steep slopes and poorly designed or ineffective SWC measures were cause factors for perpetual soil erosion problems, a combination of circumstances they perceived were too difficult to overcome. They however, did not see any linkage between the on-going erosion with tall trees, poor soil-cover and the up-down tillage practices. Though farmers were aware of many SWC measures, some indigenous and others 'foreign', the implementation was limited to a few of the known conservation measures. The most important constraints were lack of capital and tools, labour shortage and construction know-how.

Having confirmed that farmers were aware of the on-going soil erosion problems, it was necessary to establish the consensus list of local soil erosion indicators. This would be useful in assessment of soil erosion in other regions of the East African highlands and facilitate fieldworkers to communicate with farmers when discussing land degradation. How farmers described the erosion indicators in the local language and how these indicators evolved on the cultivated hillslope was captured through a household survey and transect walks in the area after rainfall seasons. It was established that though farmers may not quantitatively state the amount of soil loss that they had lost from their fields they used certain categories of erosion indicators to estimate the rate of soil erosion, in a season or a rainfall event. As such on basis of this knowledge on soil erosion indicators, they were able to distinguish between a productive and non-productive field segments. Farmers believed that when erosion indicators appeared in a field that was having conservation measures then it implied that the conservation measures were not effective in counteracting the soil erosion process.

Whereas use of such indicators could provide more reliable on-site evaluations of erosion status than conventional approaches (e.g. runoff plots and models), which most field experts have limited information about; no attempt has been made to establish their quantitative values. This research undertook to attach empirical values to these indicators so that an infield tool could be developed for fieldworkers to quickly assess level of soil erosion or crop yield decline. These two variables are most varying and yet central to the development of technologies addressing improved soil productivity. Using plot and field measurements, categories of soil erosion indicators were isolated and quantified in terms of soil loss rates and crop yield gap experienced when erosion attains to exhibit the identified erosion indicators. The study shows the importance of rill-related attributes for estimating soil loss rate. It also indicated that more of the eroded sediment were sourced within the rill channel than sheet erosion processes. Two simple equations resulted from the regressions between both the changes in topsoil profile and rill incision and the total soil loss. These equations underscored the importance of using rill length, rill width and depth, and topsoil pedestal height variables in erosion estimation. Therefore the regression equations were only applicable in situations where erosion processes had attained rill erosion processes given their significance in steep sloping landscapes to soil loss. With regard to impact of soil erosion on crop yields levels, it was established that crop yields tended to decline with increase in both the physical and chemical topsoil characteristics. Soils experiencing sheet and rill erosion processes, and soil colour change from dark to red indicated that farmers were experiencing a maize grain yield gap of up to 60 percent. By allowing erosion process to attain to the scale of subsoil exposure of soil stoniness profile implied maize grain yield gap of between 60-80 percent. This kind of information could be important for extension experts to know and be able to associate topsoil characteristics to either the rate of soil loss or crop yield gap experienced by the farmers. Such evidences could assist experts in initiating discussions and developing possible measures the farmer needed to implement to improve soil productivity.

The general belief that farmers' knowledge of soil surface morphology can be useful in mapping of the status of soil erosion was compared with scientific approach. Farmers use topsoil profile characteristics to distinguish between eroded and non-eroded soils. Therefore comparing the two concepts could improve fieldworkers' assessment of soil erosion. Despite the difference in the methodology there was strong agreement at transect scale and a 56 percent correct match in erosion classification at catchment scale. It was observed that disparities in erosion classification could be reduced when a one-class over or under-predictions were presumed as an acceptable error. This study therefore pointed at the need to utilise farmers in representation of soil degradation scenarios, since they realistically depicted the local soil conditions in their perspective. Their scenario could remain useful in circumstances where fieldworkers were not certain of the outcome of conventional scientific planning tools. This would greatly motivate farmers to participate in resource evaluation in their local ecology and own the outcome of the expert recommendations.

After assembling farmers' diverse knowledge of soil erosion processes two simple infield tools were developed and evaluated in a catchment area. The tools emphasises the use of local farmers, and not experts, in mapping indicators of erosion by which they would be able to quantify the extent and effect on soil productivity damage across the catchment area. The first tool produces a soil erosion patterns map showing the associated crop yield levels. Reflecting on the soil erosion map the farmers recommended a plan of soil and water conservation measures at catchment scale considering both the individual farms and public areas. The second tool undertakes to assist farmers to beware of the financial commitments regarding implementation of soil and water conservation measures. For each farmer category cash flow is generated, showing streams of benefits in future time steps and identifying differences in socio-economic and biophysical settings. These tools were observed to bring widescale awareness on the extent of soil erosion and pinpointing individual fields and public areas that were sources of overland flow. The tools remarkably improved decision-making capability of farmers after they had had a fore-knowledge of the costs and benefits of implementing conservation options. They also enhanced communal interests especially in cost-sharing on construction of cut-off-drains to avoid overland flow damage from upslope fields. These tools could therefore greatly complement the efforts in the Catchment Approach: a widely adopted concept in the East African highlands, for soil and water conservation activities.

Samenvatting en conclusies

In de humide centrale hooglanden van Kenia is degradatie van het natuurlijk milieu wijdverbreid. Deze degradatie komt al voor sinds de koloniale tijd. De factoren die maken dat de kwetsbare hooglanden makkelijk degraderen zijn onder andere steile hellingen, hoge regenvalintensiteit en bevolkingsdruk. Als gevolg van de gunstige condities voor landbouwproductie is de druk op het land een steeds weer beperkende factor voor elke poging om de voedselproductie te verhogen teneinde te voldoen aan de vraag van de bevolking. Eén van de manieren om de degradatie van het natuurlijk milieu tegen te gaan is door bodem- en waterconserveringsmaatregelen af te dwingen.

Alhoewel er op verschillende manieren is geprobeerd om boeren conserveringsmaatregelen te laten installeren, weigeren kleine boeren ze toe te passen. Tijdens het koloniale tijdperk werd gebruik gemaakt van macht en druk, hetgeen echter niet resulteerde in een positief resultaat. Ook na de onafhankelijkheid leidde diverse andere benaderingen niet tot een halt aan de vermindering van de bodemproductiviteit. Het gebruik van incentives bleek niet duurzaam, en de individuele benadering van boeren evenmin. Als gevolg van het falen van de verschillende methoden van aanpak werd de Stroomgebiedsaanpak geformuleerd. Deze aanpak streeft ernaar om boeren in een afgebakend gebied te mobiliseren en er voor te zorgen dat alle bedrijven in het gebied onder conserveringsmaatregelen komen te liggen, resulterend in een uniforme conservering binnen een periode van één jaar.

Ondanks diverse veranderingen in de methodologische aanpak, bleek het concept van de Stroomgebiedsaanpak niet te leiden tot het behalen van de doelen. Het bleek met name onmogelijk om de boeren mee te laten denken om zo een volledig begrip te krijgen in de problemen die de verhoging van de productie belemmeren. Hierdoor was er een gebrek aan kennis van boeren in alle stadia van de Stroomgebiedsaanpak. De experts die de aanpak implementeerden vertrouwden voor het grootste deel op hun eigen expertise op het gebied van bodemerosie. De boeren werden beschouwd als onwetend en er werden aanbevelingen gedaan zonder de boeren volledig op de hoogte te brengen van de financiële gevolgen. De aanpak om op stroomgebiedniveau bodem- en waterconserveringsplannen te maken faalde daarom en men gaf de voorkeur aan het werken met individuele bedrijven. Als gevold van deze mislukking werd een nieuw project geïnitieerd, wat tot doel had om simpele participatie instrumenten te ontwikkelen waarmee de Stroomgebiedsaanpak kon worden verbeterd. Dit nieuwe project richtte zijn activiteiten op de hooglanden van Oost Afrika. Deze thesis rapporteert over de activiteiten van één van de sub-projecten, in een representatief deel van de humide hooglanden aan de voet van Mount Kenya; het Gikuuri stroomgebied in het Embu district, Kenia.

Om inzicht te verkrijgen in de kennis en perceptie van boeren op het gebied van bodemerosie problemen werden bestaande bodem- en waterconserveringsmaatregelen geïnventariseerd en de mogelijke beperkingen in kaart gebracht die een ruime adoptie van deze maatregelen in de weg staan. Op basis van informatie van sleutelfiguren zijn drie landmanagement klassen gedefinieerd; vervolgens werden er discussies gevoerd met de gemeenschap en werden er met 120 boeren (gelijkelijk verdeeld over de drie klassen) op huishoudniveau interviews gehouden. Uit deze discussies en interviews bleek dat boeren niet onwetend zijn over bodemerosie. Van de 120 boeren gaf 98 % aan dat ze erosie ervaren, hetgeen bevestigd werd doordat zij in het interview verschillende erosieindicatoren in hun velden benoemden. De boeren gaven ook aan dat zij geen invloed hebben op de oorzaken van deze erosie in hun velden. Ze gaven aan hoe regenval, runoff van bovenstroomse velden, steile hellingen en slecht ontworpen of ineffectieve BWC maatregelen de onderliggende oorzaken zijn van de bodemerosieproblemen; een combinatie van omstandigheden welke zij te ingewikkeld achten om zelf op te lossen. De boeren zagen geen verband tussen erosie en hoge bomen, slechte bodembedekking en ploegen in de hellingsrichting. Alhoewel boeren goed op de hoogte bleken te zijn van BWC maatregelen, traditionele als geïntroduceerde, was de implementatie van BWC maatregelen beperkt tot slechts enkele van de bekende conserveringsmaatregelen. De belangrijkste beperkingen die werden gemeld waren: gebrek aan kapitaal en materieel, arbeidstekorten en gebrekkige technische kennis.

Nadat door het onderzoek werd bevestigd dat boeren zich bewust zijn van erosieproblemen, was het nodig om een lijst van erosieindicatoren samen te stellen. Deze lijst zou kunnen worden gebruikt bij het vaststellen van erosie in andere delen van de Oost-Afrikaanse hooglanden en de communicatie over landdegradatie tussen veldwerkers en boeren vergemakkelijken. Door middel van vragenlijsten en het lopen van transecten door het gebied in de periode na het regenseizoen is vastgesteld op welke wijze boeren de erosieindicatoren beschrijven in de lokale taal en ook hoe het verloop is van deze indicatoren langs de helling. Er is geconstateerd dat alhoewel boeren niet een kwantificatie geven van de hoeveelheid bodemverlies van hun velden, zij wel categorieën van erosieindicatoren gebruiken om de ernst van de erosie te schatten, zowel na een enkele bui als over de periode van een heel seizoen. Op basis van deze kennis over de bodemerosieindicatoren zijn de boeren in staat om onderscheid te maken tussen productieve en onproductieve delen van hun velden. Boeren zijn van mening dat, indien er erosieindicatoren optreden in een veld waar conserveringsmaatregelen genomen zijn, hieruit blijkt dat de conserveringsmaatregelen niet effectief zijn in het tegenhouden van erosie.

Alhoewel het gebruik van indicatoren zou kunnen leiden tot betrouwbaardere evaluaties van de lokale erosietoestand dan de conventionele aanpak omdat de experts slechts een beperkte hoeveelheid informatie hebben (b.v. runoff plots en modellen); is er geen poging ondernomen om de indicatoren te kwantificeren. Dit onderzoek ondernam wel een poging om empirische waarden aan de erosieindicatoren te koppelen. Hiermee kon een instrument ontwikkeld worden waarmee een veldwerker een snel oordeel over de erosie of de productieafname kan maken. De twee variabelen zijn zeer variant, maar staan centraal in de ontwikkeling van technologieën die een verhoogde productiviteit beogen.

Door middel van metingen op plot- en op veldniveau zijn categorieën van erosieindicatoren geïdentificeerd en gekwantificeerd in termen van bodemverliezen en opbrengst verliezen ten opzichte van situaties zonder erosieindicatoren. Deze studie toont het belang van rill-eigenschappen aan voor het schatten van erosie. Er is aangetoond dat het grootste deel van het geërodeerde materiaal afkomstig is van rill-erosie en niet van sheet-erosie. De regressie tussen zowel de veranderingen in de toplaag van de bodem als de diepte van de rills met de totale bodemverliezen resulteerden in twee eenvoudige formules. Deze formules geven het belang aan van het gebruik van de lengte van de rill, de diepte van de rill en de pedestal hoogte aan het bodemoppervlak voor het schatten van de erosie. Als gevolg hiervan zijn de regressie formules slechts geldig in die situaties waarin het erosieproces reeds het stadium van rill erosie bereikt heeft.

Met betrekking tot de gevolgen van bodemerosie op de gewasproductie is er vastgesteld dat de productiviteit van het gewas afneemt bij toename van indicatoren van zowel de fysische als de chemische karakteristieken van de toplaag van de bodem. Bodems waarop sheet- en rill-erosie processen optraden en waar de bodemkleur veranderde van donker naar rood wezen erop dat boeren een maïsoogst reductie tot 60 procent ervoeren. Bij het bereiken van het blootleggen van de stenige ondergrond trad een reductie van 60-80 procent in de maïsoogst op. Dit soort informatie is van belang voor de landbouwvoorlichters aangezien hiermee door middel van een beoordeling van de toplaag karakteristieken van het bodemoppervlak een oordeel over de mate van erosie of het productieverlies kan worden gemaakt. Met behulp van dergelijk bewijs kan de voorlichter de discussie met de boeren aangaan en mogelijke maatregelen ontwikkelen die de boer zou kunnen uitvoeren om de bodemproductiviteit te verhogen.

De aanname dat de kennis van boeren over de bodemmorfologie zou kunnen worden gebruikt om de ernst van de erosie te bepalen is getoetst aan een wetenschapppelijke benadering. Boeren gebruiken de karakteristieken van de toplaag van de bodem om het verschil te beschrijven tussen geërodeerde en niet geërodeerde bodems. De gangbare wetenschap gebruikt afstromings proefvelden en modellen. Een vergelijking van deze twee concepten zou nuttig kunnen zijn om de beoordelingscapaciteit van de veldwerkers te verbeteren. Alhoewel er een groot verschil was in aanpak was er een sterke overeenkomst op de schaal van het transect, en 56 % overeenkomst van de erosie classificatie op stroomgebiedschaal. Verschillen in erosie classificatie kunnen worden verminderd door de over- en ondervoorspelling van één klasse als acceptabel te beschouwen. Deze studie wijst daarom op het belang van het gebruik van boeren bij het maken van bodemdegradatiescenario's, omdat deze op realistische wijze de lokale bodemcondities vertegenwoordigen. Ook in het geval veldwerkers niet zeker zijn van de resultaten van conventionele wetenschappelijke planningstools, blijven de scenario's hun nut behouden. Het gebruik ervan zou boeren stimuleren om te participeren in de evaluatie van de natuurlijke hulpbronnen en hierdoor zouden boeren de resultaten van expert aanbevelingen als hun eigendom zien.

Nadat de kennis van boeren op het gebied van bodemerosie was vastgelegd zijn er twee eenvoudige hulpmiddelen ontwikkeld om in het veld te gebruiken en in het stroomgebied geëvalueerd. De tools benadrukken de betrokkenheid van boeren (en niet de experts), bij het vaststellen van erosie indicatoren waarmee de mate en de verspreiding van de bodemproductiviteitschade in het stroomgebied kan worden vastgesteld. Het eerste tool resulteert in een bodemerosiepatroonkaart waarop tevens de oogstniveau's staan aangegeven. Als reactie op deze kaart reageerden de boeren met een plan van aanpak voor bodem en waterconserveringmaatregelen, waarbij zowel individuele bedrijven als openbare gebieden betrokken waren. Het tweede tool heeft als doel om boeren te begeleiden bij het aangaan van financiële verplichtingen van bodem- en waterconserveringsmaatregelen. Voor elke boer wordt een cashflow categorie gegenereerd, waarin de voordelen per toekomstige tijdstap zichtbaar worden. Ook wordt het verschil in de socio-economische en biofysische situatie geïdentificeerd. De tools resulteerden in een wijdverspreid bewustzijn van de mate en verspreiding van erosie en wezen op die velden en openbare gebieden die de bron waren van de oppervlakkige afvoer van regenwater. Met behulp van de tools werd de beslissingsvaardigheid van de boeren sterk verbeterd, met name doordat zij van te voren op de hoogte waren van de financiële gevolgen van de implementatie van de verschillende conserveringsopties. De boeren toonden ook een gemeenschapszin met name op het gebied van het delen van de kosten voor de drainagae van oppervlakkige afvoer. De tools zullen hierdoor een geweldige aanvulling zijn op de bestaande in Oost Afrika veel toegepaste Stroomgebiedsaanpak.

ANNEX

TOOL FOR PARTICIPATORY SOIL EROSION MAPPING

Tool for participatory soil erosion mapping

The soil erosion-mapping tool consists of six steps (Fig. 1), which are all described in this chapter. The tool shall be applied in an area already identified for establishing soil and water conservation activities. This implies that the farmers in the area have recognised soil erosion problem and they are willing to participate in undertaking conservation on their farms. Each of the six steps is explained in general terms in this chapter, therefore allowing adaptation to different circumstances.

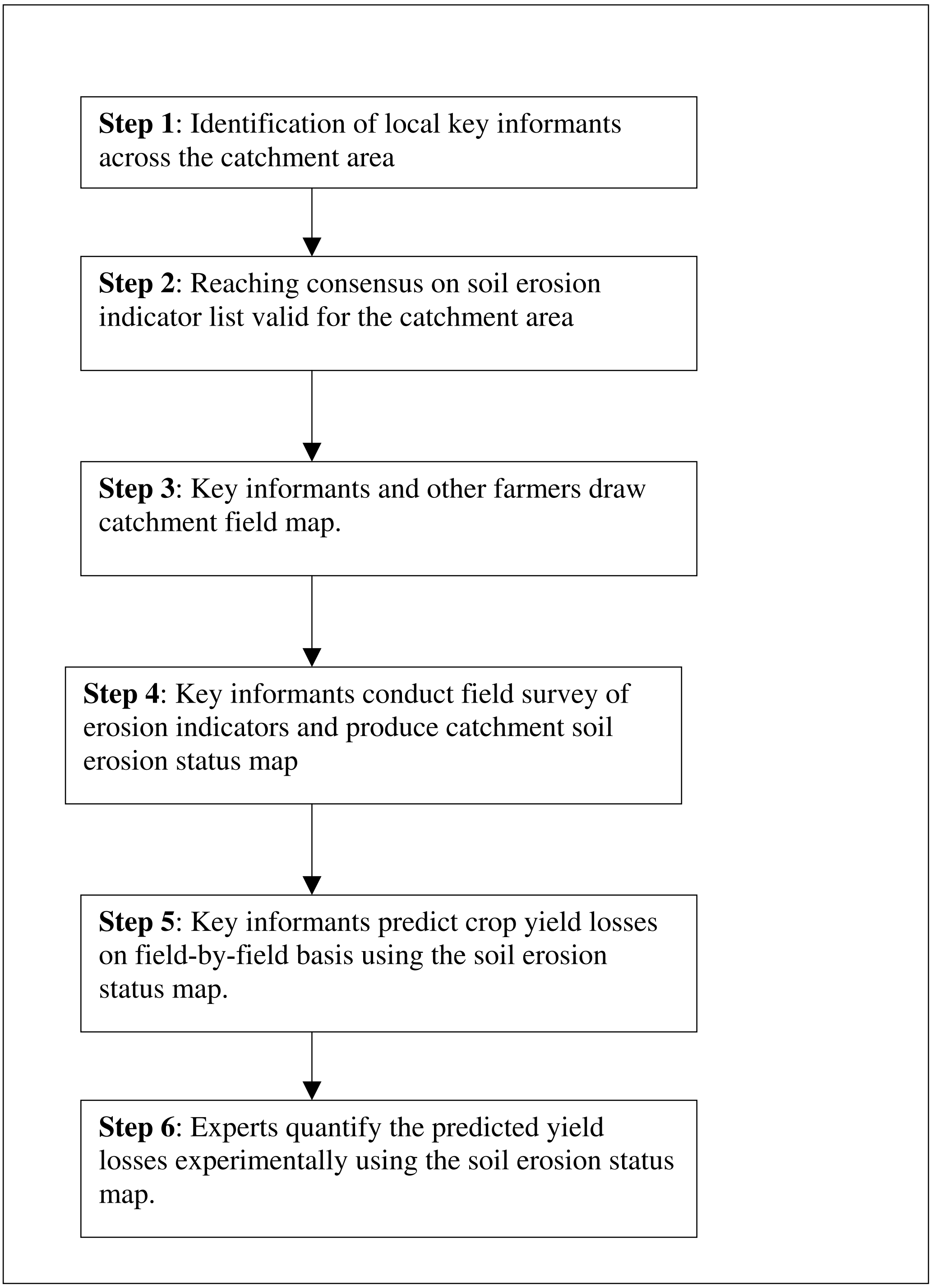

Figure 1. Steps in the tool for mapping of soil erosion using farmers' indicators.

Step 1: Identification of local key informants across the catchment area

Aim: *Identify key informants whose homesteads are evenly distributed in their individual villages so that they assist in subsequent steps.*

Expected outputs: List of key informants representing each catchment village units

Activity: Firstly, a team of key informants is carefully selected. The village leaders' knowledge of the farmers in their respective villages could be applied in identification of suitable key informants. It is imperative that this team is gender balanced and as much as possible in equal proportion of both genders. Number of key-informants to select in each village should depend on the size of the village. Once identified, the experts applying this tool need to brief the key informants on their role.

> **"When dealing with women in a group activity, punctuality in executing the planned work must be adhered to, otherwise they are likely to politely depart before the planned activity is commenced or finalised…for reasons related to household chores"**

Step 2: Reaching consensus on soil erosion indicator list valid for the catchment area

Aim: *Establishing consensus knowledge of erosion indicator and their severity ranking.*

Expected outputs: Consensus list of soil erosion indicators and their relative severity ranking

Activity: A public meeting during a focussed PRA, in the selected area e.g. a catchment area, can be organised for the farmers to generate a list of soil erosion indicators. With this list the key informants could then make transects across the landscape in the catchment area ensuring that all types of topographies prone to erosion impact are visited. The survey needs to be undertaken after a rainfall season. Besides this transect walk being a familiarization opportunity for some of the key informants, more other erosion indicators are likely to be identified to add to the list generated during the public meeting. After this it's advisable to present the final list of indicator to the farmers in the study area during another public meeting. Once all agree, the consensus list of soil erosion and sedimentation indicators is established. The farmers could also indicate which of the indicators signify the current and past erosion processes.

> **Current indicators are those erosion features that develop after a short period of rainfall events but tillage or human movements can easily destroy their evidence. Past erosion indicators indicate longterm recurrence of erosion and cannot be easily reversed or obliterated by tillage operations alone.**

Box 1. Key informants (farmers) identifying and recording the soil erosion and sedimentation indicators in cropped fields**.**

> **"My friend though I am the Soil and Water Conservation Officer in this Division, the degree of erosion is worrying and seriously higher than ever imagined"** The officer making a comment during transect walks with farmers to the project leader

During the public meeting the key informants and the rest of the farmers in the meeting can undertake to assess relative severity of importance of the consensus erosion indicators. This is carried out through pair wise analysis and ranking of indicators (Box 2). The results shall show which indicators influences more severe impact on soil productivity, than the other, according to the farmers' knowledge and perceptions. The exercise involves taking one indicator at a time and seeking consensus opinion on whether its development implies more severe soil erosion damage than each of the listed indicators. The outcome of this exercise is the frequency counts of each of the listed indicators. The most frequently mentioned indicator is the severest indication of erosion process. The experts e.g. extension agents could however express the frequency counts as a ratio of the total frequency counts per indicator to the total frequency counts of the listed indicators. An example of the result is shown in Table 1, based on perceptions of farmers in Kenya and Tanzania. The weight ratio can be used for quick assessment of the erosion impact in areas with different distribution of soil erosion indicators.

Box 2. Farmers agreeing on indicator severity ranking using pairwise analysis

Table 1. Example of consensus erosion indicators and relative weights in the two sites; Gikuuri (Kenya) and Kwalei (Tanzania) catchments in 2003.

Consensus erosion indicators	Weight ratio	
	Kenya	Tanzania
Bareness**	n/a	0.13
Gullies**	0.17	0.11
Rock outcrop**	0.11	0.11
Stoniness**	0.14	0.10
*Mashuhee***	n/a	0.09
Rills*	0.09	0.08
Red soils**	0.12	0.08
Colour of runoff*	n/a	0.07
Coarse sediments on land surface**	n/a	0.06
Yellow plant colour**	na	0.04
Steep slopes (>70%)*	n/a	0.04
Low crop yields**	n/a	0.04
Broken SWC structures*	0.15	0.02
Sedimentation*/**	0.06	0.02
Loose soils**	0.02	0.02
Splash pedestals*	0.03	0.01
Sheetwash*	0.05	n/a
Root exposure*/**	0.08	n/a

Note: *current erosion indicators; **past erosion indicators; na= where indicators were not identified directly as a consequence of soil erosion or farmers did not mention it.

Step 3: Key informants and other farmers draw catchment field map.

Aim: *Sketch the catchment field map*

Expected outputs: Catchment field map

Activity: The key informants and the rest of the farmers in the village plan for a meeting. The purpose is to sketch the catchment area map, which shows the plan of all the field holdings identifying their respective owners. The sketching of the map by the farmers is possible since the key informants ought to have been drawn from the villages within the catchment. So their knowledge of the respective villages should be quite adequate to undertake household field delineation and identification of the owners by name.

Firstly, the key informants are asked to sketch out the outline of the catchment external boundary by the expert implementing the tool. They could use any local materials available to ensure the boundary line is clearly marked and any other features acting as benchmarks are noted within the catchment area. Once the outline has been established each key informant team can now identify on the map the approximate location of their villages. Upon which they can mark the outline boundary of their individual villages. Once all the key informants have marked the outline of village boundaries on the map, and it's agreeable among them, the mapping of the individual field holdings could start. The farmers attending meeting would check the accuracy of the field plans in the area (Box 3).

Secondly, once the catchment field map has been drawn and all village leaders agree, the experts should transfer a copy of the same sketch map from the ground/floor to a sheet of paper and whose accuracy and details must be verified by the key informants (see the final catchment field map in Box 3, at the bottom).

Box 3. Each village groups delineates their field boundaries within the catchment area

"Some of us have come to know many more people in our village and which field is adjacent to which through this map drawing exercise"…a farmer acknowledging the importance of participating in map drawing

Step 4: Key informants conduct field survey of erosion indicators and produce catchment soil erosion status map

Aim: *Identification of eroded fields, establishing the degree of erosion and classification into erosion classes*

Expected output: Catchment soil erosion status map

Activity: Next step of survey is to request the key informants to visit all the fields and record the erosion indicators observed on each field holding following the sketched catchment field map. In every field the key informants checks if soil erosion and sedimentation can be seen on the soil surface layer. They shall delineate the spatial extent of erosion: sub-dividing a field into different segments according to the type of indicators and extent of damage to the soils. Besides distinguishing field segments on the ground the same delineation is marked on the respective fields on the catchment field map. All indicators observed in every field segments must also be recorded in a field notebook. Also the name of the owner of the visited field holding shall be recorded and a code name marked on the catchment field map (see example, Table 2). It is recommended that this activity take place at the end of a rainfall season, just before harvesting operations are carried out, to avoid destroying some of the evidence of soil erosion and sedimentation. Whereas the farmers, based on their experience, can estimate the severity of soil damage on basis of the indicators patterns and types (Fig. 2), the experts can determine the severity classes using the aggregation of weight ratios (using Tables 1 and 2). Finally after field-by-field visits a catchment-wide soil erosion status map is produced and a workshop to this map could be organized during which the field owners can verify the erosion classes assigned to their fields (Box 4 and Fig. 3).

" Some of these indicators we just knew them by name but today we were able to evidence them…." Statement from a key informant after field survey

" This project has given us an opportunity to picture the extent of soil erosion in our area, a situation we did not bother to discuss as a community there before and because of this gloomy picture of soil damage, possible in the near future crop yields will become lower and lower, also under threat is the source of our rivers, the …" Assistant Chief's remarks at the end of the meeting

Observation: Farmers were motivated to thinking of collective action activities seeing the extent of soil erosion beyond their individual fields.
Though catchment-wide activities were not favoured, due to bad past experiences of group work, but at hillslope scale or cluster of farmers owning adjacent fields discussed on how to overcome the common problems e.g. road runoff or neighbours field generating runoff, which was affecting downslope fields.

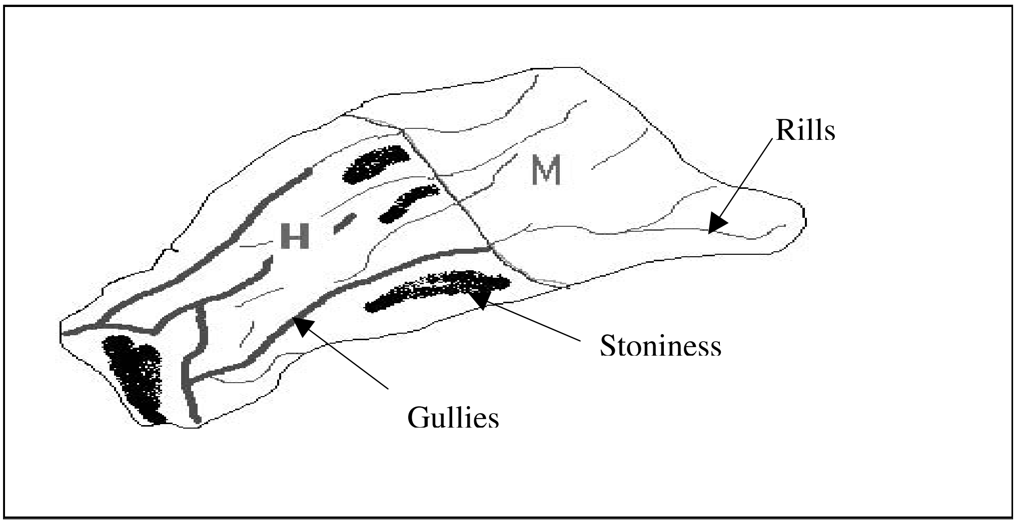

Figure 2. Farmers' erosion classification (Moderate "**M**" and High "**H**") in a field with non-uniform spread of erosion indicators.

Box 4. Farmers verifying the accuracy of key informants' assessment of erosion on their individual field holdings

During the final workshop:
Extension Officers: **"Though we learnt about soil erosion processes in college we had neither imagined to use the erosion indicators to alert farmer on the extent of soil erosion nor thought about them when advising farmers on better land management practices"**

Farmer: **"I was checking on the map to pinpoint the fields that were responsible of runoff water that floods my homestead and my vegetable garden so that I can approach the owners and discuss on how to solve the problem once and for all…we however need your intervention too"**

Table 2. Example of how an expert could assess erosion status for each of the delineated field segment.

Field portion	Indicators	Adding up indicator(s) weights	Soil erosion class*
F33-upper	Sheet, rills	Σ(0.05+0.09)=0.14	L
F33-Lower	Sedimentation, stoniness	Σ(0.06+0.14)=0.20	M
D29	Rill, red soil	Σ(0.09+0.12)=0.21	M

*Erosion risk High (H; >0.28), Moderate (M; 0.16-0.28), Low (L; <0.16)

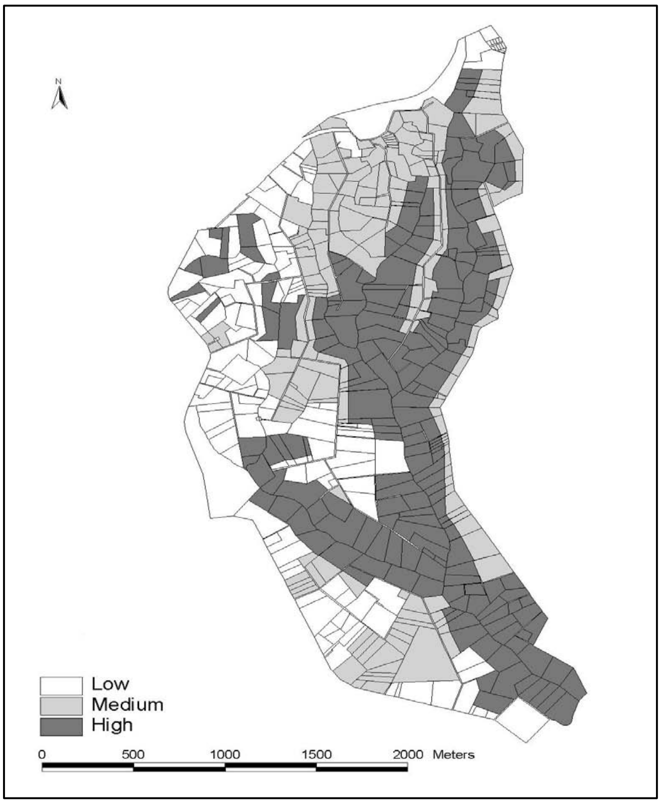

Figure 3. Soil erosion status map showing fields' erosion class

Step 5: Key informants predict crop yield losses per field based on the soil erosion status map.

Aim: *The farmers to establish association between soil loss and crop yield levels.*

Expected output: Tables showing link between erosion classes and predicted crop yield loss

Activity: This step could be carried out simultaneously with the previous step. But in case the crops were not yet mature when the previous step was carried out then this step could be undertaken at different time. The key informants visit the fields in different erosion classes, characterised by different erosion indicators and under different erosion status, and estimates (qualitatively) the crop yield loss the field owner was likely to experience during the current cropping season. The exercise can be repeated in consecutive cropping seasons to affirm the last season' information. This ensures that effects of rainfall or management bias are ruled out. See an example of data sheet in Table 3.

Table 3. An example of a survey form for erosion indicators and farmers' perceived qualitative rates of soil erosion class and crop yield loss estimates

Names of enumerators……..		Village:……………Date of visit…….	
Name of farmer	Observed erosion indicators	Predicted soil loss class (use H, M, L)	‡Predicted crop yield loss (use H, M, L)
Wilson Dan	Rills, red soil	M	H
Rop R Dawa	Gullies, stoniness	H	H
Kilimanjaro J	Rills, sheet	L	L

‡Also reflects the general physical aspects of the soils besides the listed erosion indicators. H= high, M=moderate, L=Low. Yield loss of H=50-100%, M=25-50% and L=<25%.

Step 6: Experts quantify the predicted yield losses experimentally based on the soil erosion status map.

Aim: *To establish local association between crop yield levels and soil erosion classes shown on the map*

Expected output: Experimentally quantify farmers' crop yield loss estimates

Activity: Experts can sample a number of fields within areas classified as having high, moderate and low erosion status. Also the fields the farmers perceive as having minimum erosion impact should be identified. These fields would be the reference or control standards to enable calculation of the actual local crop yield gap or loss. Such fields can be found on hill summit (ridge-crest) or protected forest or areas near the homestead . The crop yield loss or reduction can be calculated by subtracting the crop yields in the different erosion classes from the reference or control fields (Table 4). The determined crop yield loss would be useful for rough estimation of crop yields in yield differences between fields experiencing different erosion levels. This association could motivate farmer to reconsider implementing improved soil and water management strategies.

Table 4. Quantifying soil erosion status classes using crop yields.

Erosion status class	Measured crop yield (t ha^{-1})	Crop yield loss (%)
Low	3.84	5 (±5)
Moderate	2.14	48 (±15)
High	1.39	66 (±20)
REFERENCE‡	4.08	0

‡This is soil where erosion is perceived have minimum impact

Extra step 6.1:
The experts could evaluate the equivalent soil fertility levels for soils under different erosion status. For this, soil samples from the topsoil depth could be collected from all the fields, both the eroded and the hill summit fields (reference soils). An example of soil sample analysis shown below and showed a closer correlation between erosion status and the low fertility status:

Erosion status class	Levels of the most sensitive soil nutrients				
	pH	N%	P_{ppm}	$K_{me\%}$	%Org C
Low	5.28	0.22	34.40	1.26	1.74
Moderate	4.51	0.21	19.00	0.97	1.42
High	4.81	0.19	20.83	0.80	1.48
REFERENCE‡	5.23	0.24	35.36	1.46	1.66

Extra step 6.2.
Though farmers have a clear knowledge of erosion processes, they most often ignore the impact of the insidious erosion phases due to splash drops, sheet and rills until severe and irreversible indicators emerge. Therefore illustrating the correlation between crop yields and dominant soil erosion indicators, could warn farmers not to let erosion attain some classes. Example of such relationship is shown:

Erosion indicators	Maize crop yields (t/ha)	Maize grain yield loss (%)
Stoniness	0.83	79 (±20)
Sedimentation	1.89	53 (±15)
Red/loose soils	2.47	38 (±10)
Current erosion indicators (sheet-rills- root exposure)	2.49	37 (±8)
CONTROL	4.00	0

Curriculum vitae

Barrack Okoba was born on 5th December 1959 in Busia District, Kenya. Between 1970 and 1981 he received his primary and secondary education in various schools in Busia District before proceeding for his A-level education in Kapsabet School in Nandi District. In 1982 he joined Jomo Kenyatta university of Agriculture and Technology (The then JKUCAT) and successfully obtained a diploma in Agricultural Engineering in 1984. He was then employed by the Ministry of Agriculture in the scientific division, which later became part of Kenya Agricultural Research Institute (KARI), and was deployed at the National Agricultural Research Laboratories (NARL) – Kabete (Nairobi). In 1992 he obtained a scholarship from the Netherlands Fellowship Programme (NFP) to study Watershed Management and Conservation at the International Institute for Aerospace Survey and Earth Sciences (ITC) in Enschede, The Netherlands. While there he successively obtained a Post Graduate Diploma in 1993 and Master of Science (MSc) degree in 1994. His majors were in remote sensing, surface hydrology, soil erosion processes and techniques of assessing soil erosion. His MSc, with thesis, was on testing of various soil erosion assessment models in Thailand, including 'rule of thumb model'. The period at ITC gave him opportunity to experience different erosion scenarios in Malaga (Spain) and in southeastern Asia (Thailand). His interest in assessment of soil erosion using soil surface erosion features and vegetation was borne then. On returning to Kenya, at the end of 1994, he was transferred from NARL-Kabete to KARI-Embu and assigned to manage a project funded by ODA (UK) through Silsoe Research Institute between 1995-1998. The project was focussed on improvement of indigenous soil and water management technologies in the drylands of the lower Embu District. It was then that he learnt to listen to farmers and learn from their experiences. Briefly (1998-1999) he worked with an Agroforesty project that collaborated with ICRAF-Nairobi and Kenya Forestry Research Institute (KEFRI) and at the same time helped to coordinate the central Kenya benchmark site activities of a regional program known as African Highlands Initiative (AHI). At the end of 1999 a project known as EROAHI, funded by Methodological Support to Ecoregional Programmes (under ISNAR), incorporated him in its activities as the site manager at Embu, Kenya. Towards the end of 2000 he enrolled as a sandwich PhD student at Wageningen University in the Erosion and Soil & Water Conservation Group. He is currently working as a soil and water management senior scientist with KARI at Embu Centre. He can be contact through: Okoba2000@yahoo.com

PE&RC PhD Education Statement Form

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)

The C.T. De Wit Graduate School PE&RC PRODUCTION ECOLOGY & RESOURCE CONSERVATION

Review of literature

- Quantification of Soil Erosion and Sedimentation Indicators in central highlands of Kenya (2001)

Post-Graduate Courses

- Land-use planning (2001)
- Advanced Statistics (2002)

Deficiency, Refresh, Brush-up and General courses

- Processes and modelling of erosion and SWC (2000)
- Social and economic aspects of SWC (2000)
- Scientific Writing (2001)

PhD discussion groups

- Agricultural production systems in temperate systems (2002-2003)
- KARI CRAC: Annual centre projects assessment and needs discussion team (2002-2003)

PE&RC annual meetings, seminars and Introduction days

- Ethics in Science (2002)

International symposia, workshops and conferences

- ISCO–China (China, 2002)
- ASA-CSSA-SSSA annual meeting (USA, 2003)

Laboratory training and working visits

- KARI-NARL, Nairobi-Kabete. Soil physical and chemical anlysis methods (Kenia, 2003)