ARTICLE IN PRESS

+ MODEL

Available online at www.sciencedirect.com

SCIENCE DIRECT

GEODERMA

Geoderma xx (2006) xxx – xxx

www.elsevier.com/locate/geoderma

Indicators of soil quality: A South–South development of a methodological guide for linking local and technical knowledge

E. Barrios [a,*], R.J. Delve [b], M. Bekunda [c], J. Mowo [d], J. Agunda [e], J. Ramisch [f], M.T. Trejo [g], R.J. Thomas [a,1]

[a] *Tropical Soil Biology and Fertility Institute of Centro Internacional de Agricultura Tropical (TSBF-CIAT), A.A. 6713, Cali, Colombia*
[b] *TSBF-CIAT, Kampala, Uganda*
[c] *Department of Soil Science, Makerere University, Kampala, Uganda*
[d] *African Highlands Initiative, Lushoto, Tanzania*
[e] *CARE, Homa Bay, Kenya*
[f] *TSBF-CIAT, Nairobi, Kenya*
[g] *TSBF-CIAT, Tegucigalpa, Honduras*

Received 15 March 2005; received in revised form 27 September 2005; accepted 26 December 2005

Abstract

The increasing attention paid to local soil knowledge results from a greater recognition that farmer knowledge can offer many insights into the sustainable management of tropical soils and that the integration of local and technical knowledge systems helps extension workers and scientists work more closely with farmers. A participatory approach and a methodological guide were developed to identify and classify local indicators of soil quality and relate them to technical soil parameters, and thus develop a common language between farmers, extension workers and scientists. This methodological guide was initially developed and used in Latin America and the Caribbean-LAC (Honduras, Nicaragua, Colombia, Peru, Venezuela, Dominican Republic), and was later improved during adaptation and use in eastern African (Uganda, Tanzania, Kenya, Ethiopia) through a South–South exchange of expertise and experiences. The aim of the methodological guide is to constitute an initial step in the empowerment of local communities to develop a local soil quality monitoring and decision-making system for better management of soil resources. This approach uses consensus building to develop practical solutions to soil management constraints identified, as well as to monitor the impact of management strategies implemented to address these constraints. The particular focus on local and technical indicators of agroecosystem change is useful for providing farmers with early warnings about unobservable changes in soil properties before they lead to more serious and visible forms of soil degradation. The methodological approach presented here constitutes one tool to incorporate local demands and perceptions of soil management constraints as an essential input to relevant research for development activities. The participatory process followed was effective in facilitating farmer consensus; for example, about which soil related constraints were most important and what potential soil management options could be used. Development of local capacities for consensus building constitute a critical step prior to

---

[*] Corresponding author. Fax: +57 2 4450073.
E-mail address: e.barrios@cgiar.org (E. Barrios).

[1] Current address: International Center for Agricultural Research in the Dry Areas (ICARDA), PO Box 5466, Aleppo, Syria.

doi:10.1016/j.geoderma.2005.12.007

collective action by farming communities resulting in the adoption of integrated soil fertility management strategies at the farm and landscape scale.

Keywords: Soil quality; Integrated Soil Fertility Management (ISFM); Local knowledge; Participatory approaches; Latin America; Africa; South–South exchange

1. Introduction

Human-related activities play a major role in promoting soil degradation through deforestation, overgrazing, inappropriate tillage, nutrient mining, salinization and acidification. It is estimated that close to 85% of tropical soils have some degree of degradation (Oldeman and Van Lyden, 1998). There is increasing evidence that land degradation induced by agriculture has been promoting a gradual shift away from the high input agriculture paradigm, based on overcoming soil constraints with fertilizers, lime, biocides and tillage to fit plant requirements, towards a paradigm with greater reliance on soil biological processes (Sánchez, 1994). This more ecological approach is based on adapting germplasm to adverse conditions, enhancing the biological activity of the soil and optimizing nutrient cycling to minimize external inputs and maximize the efficiency of their use. More recent conceptual developments have led to the emergence of the Integrated Soil Fertility Management (ISFM) paradigm (Defoer and Budelman, 2000; TSBF-CIAT, 2005). ISFM is a holistic approach to soil fertility research that embraces the full range of driving factors and consequences, biological, physical, chemical, social, economic and political, of soil degradation. There is a strong emphasis in ISFM research on understanding and seeking to manage the processes that enable change.

Paradigm shifts may allow us to see and understand the world in new ways, but unless their implications are internalized and accepted by farmers they will not yield beneficial impacts through adoption of improved soil management options and healthier landscapes. The limited adoption of new technologies and new cropping systems is now being recognized as closely related to the failure to take into account the local experience and needs of farmers (Warren, 1991). The limited understanding of underlying causes of ecological change induced by land management creates uncertainties that may also prevent adoption because of perceived high risks (Oberthur et al., 2004). Uncertainty, however, can be reduced by relevant scientific knowledge that integrates local knowledge (Barrios and Trejo, 2003).

Increased concern about soil management as a key determinant of agricultural sustainability (Lal and Stewart, 1995) has promoted the need to define soil quality and identify suitable indicators to monitor changes in soil quality as affected by land use and soil management (Doran and Parkin, 1994; Doran and Jones, 1996; Pankhurst et al., 1997; Schjonning et al., 2004). Soil quality has been defined in many ways, but here we use Doran and Parkin (1994) definition according to which “it is the capacity of a soil to be functional, within the limits imposed by the ecosystem and land use, to preserve the biological productivity and environmental quality, and promote plant, animal and human health”. Given that the soil keeps a unique balance among its physical, chemical and biological factors, soil quality indicators should also be made up of combinations of these factors, especially in those situations where some integrative parameters (i.e., water infiltration rate, soil respiration) reflect simultaneous changes in soil physical, chemical and biological characteristics.

Ethnopedology, the study of local knowledge about soils and their management, has been increasingly recognized for its contribution to the evaluation of land use in relation to soil quality and sustainable agriculture (Winklerprins and Sandor, 2003). Our objective was to study the process of developing a participatory methodological approach to identify and classify local indicators of soil quality, finding their correspondence with technical indicators of soil quality, and facilitating the integration of local and technical knowledge about soils and their management. Furthermore, it also documents the impact of the South–South transfer of this methodological approach developed in Latin America to the east African context on higher education, Makerere University (Uganda), a regional organization, African Highlands Initiative (Tanzania) and an international NGO, CARE-Kenya (Kenya).

1.1. Integrating local and technical knowledge systems

The complementary nature of indigenous and technical knowledge in agriculture has been increasingly acknowledged (Altieri, 1990; Barrios et al., 1994; Walker et al., 1995; Sandor and Furbee, 1996; Winklerprins, 1999). While experimental research provides information that can help farmers make better decisions, scientific approaches alone are insufficient for addressing the sustainable management of agroecosystems. The limited success of top-down approaches to management of tropical soils that have excluded farmer insights has led to an increased recognition that local knowledge is a key resource for the sustainable management of tropical soils (Hecht, 1990; Barrios and Trejo, 2003; Oberthur et al., 2004).

Local knowledge related to agriculture includes the intuitive integration of indigenous skills, systems knowledge and suitable technology options, resulting from direct interaction with the environment (Altieri, 1990). Information refined and transferred across successive generations produces a system of understanding of natural resources and relevant ecological processes (Pawluk et al., 1992). Nevertheless, while local knowledge can add local relevance and potential sensitivity to complex environmental interactions, it may not be able to keep pace with the changing sociocultural and economic dynamics in most rural environments.

Farmer's knowledge and scientific knowledge share a number of common 'core' concepts as illustrated in Fig. 1, but each knowledge system has gaps that in many cases can be complemented by each other. Indeed, because this knowledge is "local" and by definition grounded in particular circumstances, interactions with other knowledge systems (such as those integrated within "science") can help address dynamic environments.

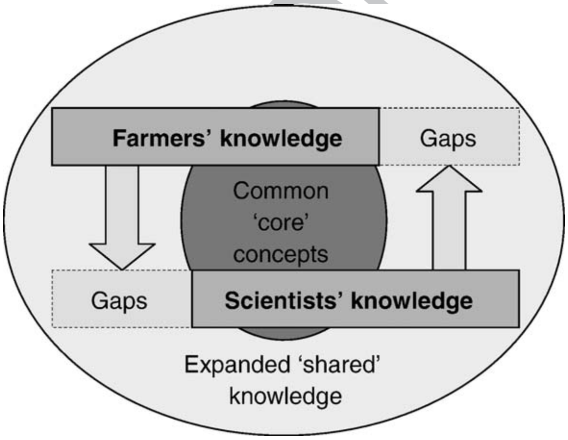

Fig. 1. Integrating knowledge systems into an expanded 'shared' knowledge.

It is thus argued that research efforts should further explore a balance between scientific precision and local relevance resulting in a "hybrid" knowledge base. It is this expanded 'shared' hybrid knowledge that we are envisioning as the goal of using the methodological approach described here. Furthermore, this approach would overcome the limitations of local knowledge, such as its site specificity and empirical nature, and would allow knowledge extrapolation through space and time (Cook et al., 1998).

The generation of "hybrid" knowledge reflects an effort to understand land management in the context of many forces interacting within a dynamic rural livelihood context. The sustainable livelihoods approach treats the deterioration of natural capital, such as soil, within the context of other, potentially equally important capitals (human, social, financial, physical). As such, it considers issues beyond a narrow disciplinary focus, like many studies on physical erosion barriers that pay little attention to socioeconomic factors such as labor costs, access to land, etc.

Considering soil management within a sustainable livelihoods context shows that smallholders rely heavily on social capital for accessing key resources, such as fertilizers (Isham, 2002) or land and labor. It also shows that human capital development through building knowledge to evaluate choices and effectively use new technologies (Schultz, 1964) must improve the adaptive capacity of land users within their social context rather than design and "transfer" new technologies as if they were socially neutral (Foster and Rosenzweig, 1995). Accepting that natural resource management knowledge is generated and held not only by individuals but also by groups and communities (Pretty and Ward, 2001) means that building new hybrid knowledge systems must also be a process of building and benefiting from increased human and social capital. The very process of integrating local and technical knowledge systems, through the creation and reinforcing of existing groups and networks, therefore also serves to increase the trust and social norms that are generated by networks of individual actors.

1.2. Development of a methodological guide

For farmers and researchers to develop acceptable, cost-effective strategies for improved soil management a common language is required to integrate local and technical knowledge about soils and their management. To facilitate this integration process and make it repeatable, a methodological guide was developed and used in Latin America and the Caribbean (Trejo et al., 1999). In a South–South exchange of methodology, the guide was further developed and adapted for use in eastern Africa (Barrios et al., 2001). Improvements made were incorporated into a revised Latin American version of the guide. This guide focuses on identifying and classifying local indicators of soil quality (LISQ) related to permanent and modifiable soil properties, and proposes simple methods that can be used by farmers, extension officers, NGOs, technicians, researchers and educators.

This methodological approach is based on the belief that for sustainable soil management to become a reality farming communities require improved capacities to better understand and manage agroecosystem function. Improved capacities of technical officers (extension agents, NGOs, researchers) to understand the strengths and weaknesses of existing local knowledge is also part of the methodology. As limited communication between the technical officers and the local farm community is often a major constraint to capacity building, the methodology deals with ways of jointly generating a common knowledge that is well understood (and "owned") by both interest groups.

Technical indicators of soil quality (TISQ) usually include basic parameters, such as, bulk density, pH, effective rooting depth, water content, soil temperature, total C and electrical conductivity (Doran and Parkin, 1994). Local indicators of soil quality (LISQ) are often more variable and include crop yield and vigor, soil color, soil texture and structure, and the presence/absence or abundance of local plant and soil invertebrate species. It should be noted that many LISQ integrate multiple aspects of soil quality in a single indicator and they are much more user friendly than complicated laboratory tests. However, even within relatively homogenous communities, farmers can hotly debate the significance and relevance of certain LISQ, particularly where contradictory indicators occur in the same plot or where the interpretation is highly subjective (Mairura et al., 2004).

Selecting a suitable set of ISQ is the first step in the conceptual model describing the development of local soil quality monitoring systems (SQMS) in Fig. 2. These ISQs are identified from the local and technical knowledge systems and critical levels would need to be defined in order to determine the main soil management limitations of the agricultural system under study. The predominant use of local and/or technical parameters, now part of a common "hybrid" knowledge, varies according to the monitoring objectives; e.g., greater reliance on local indicators if the users will be primarily farmers, clear linkages between local and technical indicators for extension agents, or integrative technical indicators for policymakers. Attention should also be paid to the inclusion of indicators that can be used while progressively increasing the scale at which results are applied (e.g., from plot to field and farm level, up to watershed, region and nation level). Some examples of such indicators might be crop yield and yield trends, land cover, land use intensity and nutrient balances (Pieri et al., 1995). More recently, Defoer and Budelman (2000) have proposed the use of resource and nutrient flows at farm scale to assess land use sustainability and local variation usually missed in studies at higher levels of aggregation (i.e., region, country).

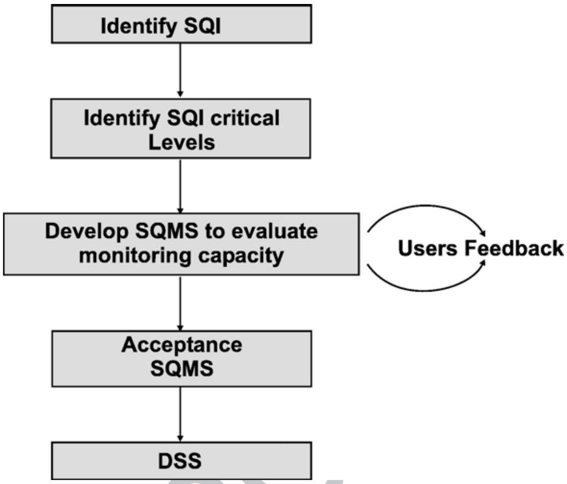

Fig. 2. Conceptual model describing process leading to the development of Soil Quality Monitoring Systems.

This phase would be followed by the definition of guidelines for the SQMS along with information on interpretation of results. User feedback is very important during this stage because it would contribute to the robustness of the SQMS and thereby should build the grounds for its acceptance. Once the SQMS is fully accepted by users, it can become a decision support system (DSS) for management of the soil resource at the farm, village and landscape levels.

1.3. Structure of the guide

The methodological guide is made up of six sections: Section 1 provides a general introduction about the management of the soil resource and the ISQ (Fig. 3). Section 2 presents a technical conception of the soil through a simplified model of soil formation (SMSF) based on Jenny's seminal work (Jenny, 1941, 1980) in order to bring participants to a common starting point. It

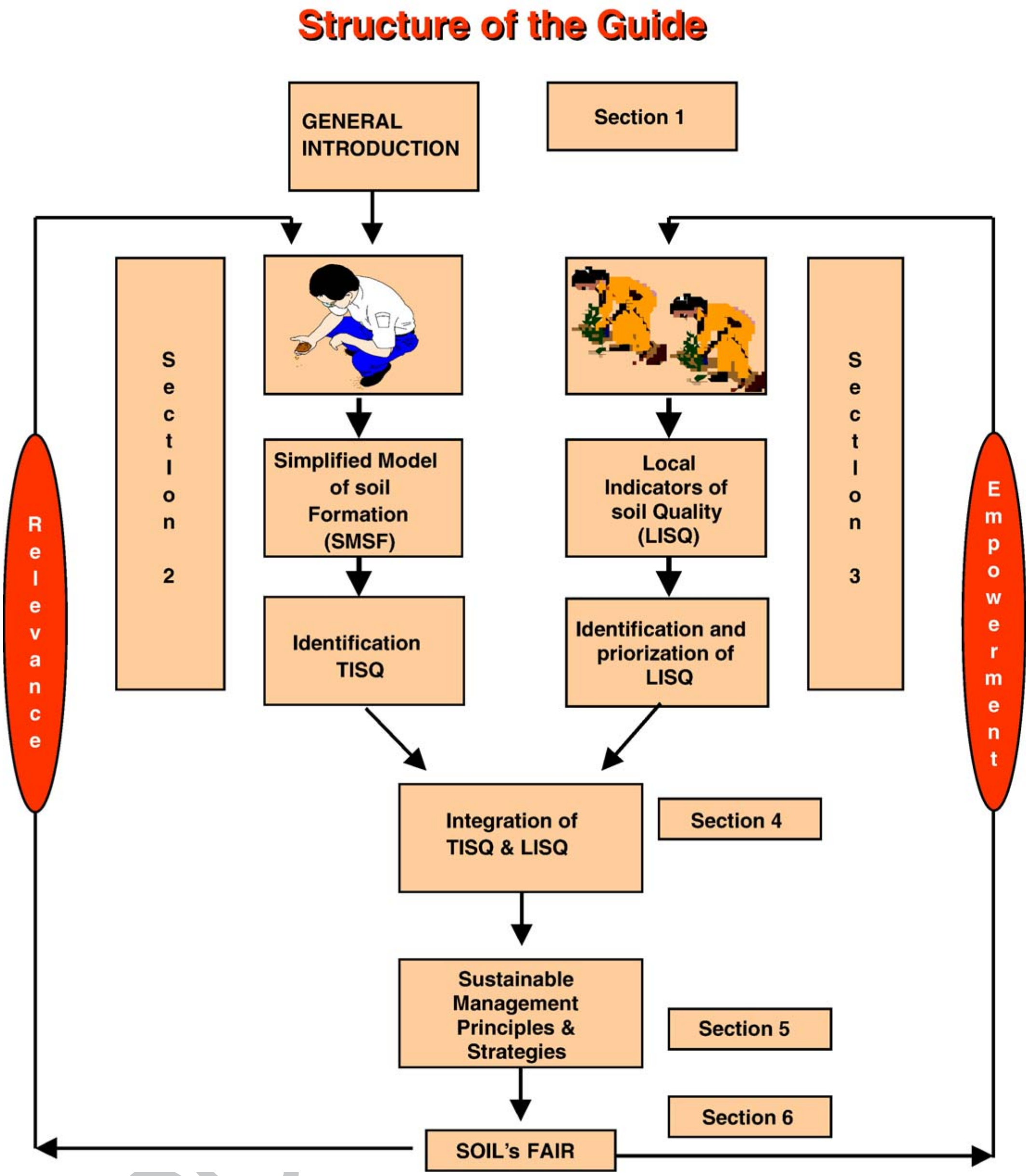

Fig. 3. Structure of the methodological guide for the identification and classification of local indicators of soil quality (adapted from Barrios et al., 2001).

also introduces the technical indicators of soil quality (TISQ) with the participation of professionals from National Agricultural Research and Extension Systems (NARES), NGOs, universities and international agricultural research centers.

Section 3 deals with participatory techniques that help gather, organize and classify local indicators of soil quality (LISQ) through consensus building processes that are conducted with local farmer communities. The process to elicit information about local indicators of soil quality starts with a brainstorming session guided by trainers where farmers explain, in their own words, how they define and classify the quality of their soils. Once local indicators have been collected, a ranking session is initiated with smaller groups of three or four farmers. Section 4 provides a methodology to construct an effective channel of communication by finding correspondence between TISQ and LISQ that facilitates better communication amongst scientists, extension agents, NGOs and farmers. This is carried out in a plenary session exercise of integration where the most important local indicators of soil quality are analyzed in the context of technical knowledge and are classified into indicators of permanent or modifiable soil properties (Table 1). Section 5 is concerned specifically with the management principles that will underpin potential strategies to address constraints modifiable in the short (<2 years), medium (2–6 years) and long (>6 years) term.

The final step, presented in Section 6, is the "Soils Fair", an activity that brings together all the previous steps in a public forum. The Fair concept is designed to help farmers reinforce their skills characterizing relevant physical, chemical and biological properties of their soils through simple methods that have been integrated with their local soil management knowledge. Here farmers and scientists communicate ideas about the way forward through jointly developed common language from the earlier steps. The Fair is also an opportunity for simple demonstrations of using the soil quality measurement tools in situ to identify local soil management and land degradation problems.

The approach summarized above provides the tools to conduct a technical–local classification of the soil, based on modifiable and permanent soil properties, which has the flexibility to work in the spatial scale continuum plot/farm/landscape (watershed) while also having the potential to take the stakeholder groups and gender issues dimensions into consideration. This guide then provides a valuable tool to evaluate the impact of the land use change on soil quality across various spatial scales and social actors. Finally, participants in the training event associated with the guide are encouraged to develop "action plans". These action plans show the commitment made by all participants to apply the methodological approach and gained insights in their own work plans and environments. There is open access to the methodological guide at http://www.ciat.cgiar.org/tsbf_institute/index.htm, the TSBF Institute of CIAT website, where it can be downloaded.

1.4. Soil quality indicators and ISFM

The concept of soil quality has been in a process of evolution as a result of progressively moving from a concept focused on yield potential and nutrient levels to one of environmental quality, food safety and human health (Karlen et al., 1997). Studies by Sarrantonio et al. (1996), despite coming from very different socioeconomic context to ours, come to similar conclusions about the need to involve farmers as active participants for on-farm assessment of soil quality. They propose a soil quality test kit that includes a minimum set of parameters like soil pH and electrical conductivity, bulk density, infiltration rate, water holding capacity, soil respiration and soil nitrate. Results to date from studies conducted in Latin America and Africa indicate that biological indicators like native flora and soil biota are among the most often cited local indicators of soil quality (Barrios et al., 2001; Birang et al., 2003; Barrios and Trejo, 2003; Velasquez, 2004). This is consistent with a review by Pankhurst et al. (1997) on biological indicators of soil health and is not surprising as biological indicators have the potential to integrate changes in soil quality by simultaneously reflecting changes in the physical, chemical and biological characteristics of the soil. Many biological indicators are related to the cycling of soil organic matter (SOM) as a key component of soil quality (Swift and Woomer, 1993; Barrios et al., 1996, 1997). SOM is important for nutrient availability, soil structure and erosion control, water retention and the transport and immobilization of pollutants. At the landscape scale the diversity of plants, soil cover and degree of soil disturbance provide important indicators of expected agroecosystem functional integrity (Knoepp et al., 2000). At plot and farm scale, biological indicators of soil quality measure the

Table 1
Matrix summarizing most important local indicators of soil quality, their technical analog, and the permanent and modifiable nature of these potential constraints, an example from Latin America

Order of importance	Indicator		Property			
	Local	Technical	P	Ms	Mm	Ml
1	Good plants, good crop, healthy looking, thick/bad plants	Yield		X		
2	Land with chichiguaste, malva/land with zacate	Vegetation type			X	
3	Loose soil porous, powdery/non-powdery	Soil structure			X	
4	New land (land use change from pasture to crops), less than 10 years of use/more than 10 years of use	Cropping history			X	
5	Soil depth (half machete, 12 in.), thick/thin soil less than 4 in.	Effective soil depth	X			

P: permanent, M: modifiable, Ms: <2 years, Mm: 2–6 years, Ml: >6 years.

processes or components of SOM accumulation and mineralization. Biological indicators often recommended include: (a) nitrogen mineralization, a measure of the release of inorganic nitrogen from soil organic matter; (b) microbial biomass, a measure of the total mass of soil microorganisms; (c) microbial biomass to total soil carbon ratios; (d) soil respiration, a sum of all CO_2 generated by biological activity in the soil; (e) respiration to microbial biomass ratios; (f) soil fauna populations, size and diversity of soil arthropods and invertebrates; and (g) rates of litter decomposition, an integrated measure involving interaction of vegetation, soil nutrient availability, micro- and macrofauna and microbial populations (Brussaard et al., 2004). There is considerable scope, therefore, to further explore the use of local knowledge about biological indicators of soil quality as a tool for guiding soil management decisions.

Other frequently mentioned LISQ include those related to crop performance (yield, vigor, leaf color and sizes, time to flowering), to soil characteristics (color, workability, depth) or to the site in question (slope, previous crop and fallowing history). However, even within rather general indicators such as those related to the age of fallows, farmers are often looking for specific components to validate or reject their assumption that the soil is "recovering" from having grown "tired" under previous cropping. For instance, native plants and soil macrofauna present in fallows, soil color and depth, water holding capacity, predominant soil particle sizes and degree of clumping provide local indicators that can be easily integrated with technical indicators of soil quality (Barrios and Trejo, 2003). The classification of local indicators into permanent and modifiable factors provides a useful division that helps farmers to focus on those factors where improved management is likely to have the greatest impact and where it is not possible (Table 1). Modifiable constraints are those that can be overcome through management, such as low nutrient and water availability, low pH, soil compaction and low soil organic matter content. The discrimination between short, medium and long term is necessary to enable selection and ranking of management strategies, particularly according to the different resource endowments of the farmers. Differentiating strategies according to how long it will take to see benefits is advantageous when farmer interest can only be sustained by activities that produce tangible results in a relatively short time. The success or failure of technologies classified as producing short-term benefits will also serve to develop the credibility and trust needed for wider adoption of integrated soil fertility management practices.

Local relevance added in this participatory process allows the identification of integrated soil fertility management strategies. Fig. 4 is an example of work in hillside environments where slope and soil quality are intimately related. Slope and soil quality can be classified according to low, medium and high levels and potential land use scenarios to overcome identified constraints shown in each of the squares that represent the interaction between particular slopes and soil qualities. For example, the recommendation for the scenario where soils have a high slope and low quality should be to keep soil under native vegetation. Other diversification and intensification options can be matched to other land use scenarios.

One important challenge is the identification of critical limits of meaningful and relevant soil quality

		SLOPE		
		LOW <15%	MED 14-45%	HIGH > 45%
LOCAL SOIL QUALITY	LOW	Improved Fallows	Leguminous Cover crops	Natural Forest
	MED	Grass-legume Pastures	High Fertility Contour Bands	D.P. Live Barriers
	HIGH	High quality Pastures	Crop Rotations	Cut & Carry Systems

Fig. 4. Linking soil quality indicators, slope and land use options.

indicators (local and technical) that can become part of a local SQMS. An important and desirable feature of ISQ is their early warning capacity. As soil degradation is a slow process, it is often the case that, by the time that soil degradation becomes visible (e.g., gullying or low yields), it is already at an advanced stage and recuperation is therefore a slow and costly process. Effective early warning indicators (i.e., soil aggregation, indicators plants) would allow farmers to make decisions to prevent, mitigate or reverse the soil degradation process.

1.5. *Convergent evolution of knowledge systems?*

The South–South cross-fertilization experience provided a unique opportunity to test the hypothesis of convergent evolution, borrowed from natural sciences, in the context of local knowledge systems. The concept of convergent evolution is related to the capacity of natural populations of organisms from distant locations to evolve in similar ways if faced with similar adaptive pressures from their surrounding environment. Our studies of local knowledge systems held by farmer communities in Latin America and Africa suggest that using this concept may be possible for soil quality indicators. Farmer communities studied in Africa (east African highlands) and Latin America (Central American and Andean hillsides) came from comparable environmental contexts where soil texture (workability), soil depth, soil organic matter (soil color), slope and other common factors played an important role in farmer decision-making. Probably, the most compelling example is associated with the native plants frequently used by farmers as biological indicators of soil quality. In Table 2, we compare rankings of indicator plants conducted by Latin American hillside farmers to characterize quality of agricultural soils with those used by African highland farmers. It is remarkable that quite often the same ubiquitous plants are ranked similarly by farmers in Latin America and Africa as indicators of soil quality (i.e., *Pteridium arachnoideum*, *Bidens pilosa* and *Ageratum conyzoides*), but also that species of the same genus are found in both continents indicating a similar soil quality condition (e.g., *Commelina difusa* and *Commelina africana*). This example also suggests the potential to find useful information at the botanical genus or family level and this would considerably facilitate the wider use of local plants as indicators of soil quality.

1.6. *Impacts of South–South collaboration*

The transfer of concepts and methodological approaches from Latin America to east Africa has had different implications to different types of partners. Here we present three examples of impacts in the higher education, regional research organization and global NGO arenas.

1.6.1. *Impact on training, research and extension functions at Makerere University, Uganda*

The Department of Soil Science in the Faculty of Agriculture at Makerere University developed a training course on ‘Decision Aid Tools for Soil Resource Management’ in order to enhance dialogue between farmers and extension service providers. The course was based on tools derived from the eastern Africa edition of the methodological guide ‘Identifying and Classifying Local Indicators of Soil Quality’ (Barrios et al., 2001) and created considerable demand for soil scientists and socioeconomic scientists from the university to work together. Development and adaptation of these tools for the course was crucial in addressing some gaps that curtail delivery of extension services on soil management, namely addressing farmers needs in a form and language that they understand.

The tools have been pre-tested with University staff, as well as with other institutions and farmers. All have expressed appreciation that the tools are simple, practical, robust and helpful to link research technologies with the understanding of farmers soil management needs. In addition to university graduates, 40 university

Table 2
Native plants as local indicators of soil quality in Latin America and Africa

Latin America			Soil quality	Africa		
Local name	Scientific name	Botanical family		Local name	Scientific name	Botanical family
Helecho marranero	*Pteridium arachnoideum*	Pteridaceae	Poor	Mashiu	*Pteridium arachnoideum*	Pteridaceae
Mangaguasca	*Braccharis trinervis*	Compositae	Poor	Ma-shuuti	*Philippia usambaresnsis*	Ericaceae
Escoba Lanosa	*Andropogon bicornis*	Gramineae	Poor	Digitaria	*Digitaria* sp.	Gramineae
Siempre Viva	*Commelina difusa*	Commelinaceae	Fertile	Olaiteteyai	*Commelina africana*	Commelinaceae
Papunga	*Bidens pilosa*	Compositae	Fertile	Enderepenyi	*Bidens pilosa*	Compositae
Hierba de chivo	*Ageratum conyzoides*	Compositae	Fertile	Olmalive	*Ageratum conyzoides*	Compositae

staff from the faculties of Agriculture, Forestry and Nature Conservation, Science, Institute of Social Research, 100 government extension staff from the districts of Iganga, Rakai and Kampala districts, farmer groups in Pallisa district, and field extension staff for NGOs (AFRICARE, CARE, Agro-Management, African Highlands Initiative and TSBF-CIAT) in Kabale district have been trained in the use of these tools. A total of 45 facilitators have been trained to apply the tools in soil productivity improvement at Farmer Field Schools in eastern Uganda. In all these trainings, the tools have been continuously evaluated and adjusted to make them much simpler and effective to aid farmers' decision-making. Based on feedback from testing of the tools, the Department of Soil Science is incorporating them in the practical-training curriculum for undergraduate students to increase their skills in communicating with farmers. A field guide that can be used both during training of students and by extension staff is now under publication. A short refresher course for service providers in soils is also being developed and will be ready in 2005.

Historically, most of the university's soil scientists believed that rigorous soil analysis should precede any advice on management. However, soil analysis is not only expensive for the majority of the smallholder farmers but essentially unavailable due to logistical difficulties. The participatory approach to determining soil quality was welcomed because it can, in a relatively short time, build the farmer's capacity to assess the status of their soil quality status and make informed decisions about soil management. Soil analyses, however, still have an important role to play when defining recommendations about the strategic management of organic residues and fertilizers.

1.6.2. Impact on the African Highlands Initiative—AHI, Tanzania

The African Highlands Initiative (AHI) is an eco-regional program dealing with Integrated Natural Resource Management in the highlands of east and central Africa. It is one of the ASARECA (Association for Strengthening Agricultural Research in east and central Africa) Networks and is convened by the World Agroforestry Centre. AHI began working in 1995 on farm-level agricultural intensification through participatory problem diagnosis, and introduction and testing of promising agricultural technologies. Through strategic partnership and participatory approaches, AHI works with multi-disciplinary teams of professionals to address the multiple constraints faced by farmers in the highlands of east and central Africa.

In Muheza district, extension staff in collaboration with AHI researchers and lecturers at the Agricultural Training Institute, Mlingano, conducted a Training of Trainers workshop for village extension officers and farmers on identifying and classifying local indicators of soil quality. Ten village extension workers were trained during May and June 2002 with a follow-up workshop in September. The aim was to empower extension workers in guiding farmers to make better informed decisions in natural resource management (NRM) through use of participatory methods for identifying and prioritizing local indicators of soil quality, integrating local and technical indicators of soil quality, and then developing soil management strategies suitable for their areas.

AHI was also asked to train extension workers working with the Soil–Water Management Research Program (SWMRG) of the Sokoine University of Agriculture in two districts in the West Pare Lowlands (WPLL) (north Tanzania) and Maswa district in the Lake Victoria basin, in a project concerned with increasing agriculture productivity under Rainwater Harvesting Systems. The sponsor of the project, DFID, wanted minimum field experimentation and soil analysis and more use of farmer's indigenous knowledge in identifying soil fertility constraints and chart out sustainable strategies affordable by farmers for improving soil productivity. A 3-day training workshop was therefore organized for each district to impart knowledge on identifying local indicators of soil quality, match them with technical indicators to have a common nomenclature accessible by all actors, and then formulate with farmers options for soil fertility improvement. This training included 20 extension workers. From the evaluation that followed, the extension workers were satisfied that through use of simple tools and participatory methods the quality of soils could be identified and classified for meaningful development of soil fertility management options for different resource endowment groups. It was observed that indicators of soil quality differ from place to place and that farmers would use multiple indicators to draw conclusions on soil quality. For example, farmers from WPLL noted that, although the weed *Striga hermonthica* was indicative of poor soils, in Maswa, it always occurred on more fertile soils than in WPLL. Low crop performance was explained as "the effect the weed has on crops" rather than an indication of low soil fertility per se, which suggests the need to confirm these local indicators with laboratory soil analysis.

At one of the pilot sites for the AHI Lushoto Benchmark Site, Kwalei, Tanzania, the methodological guide developed by Barrios et al. (2001) was applied in the identification of farmers' local indicators for soil erosion (Tenge et al., 2002). Group discussion, household surveys and transect walks were used to obtain information on farmers' indicators for soil erosion. Scientific measurements were done on those fields to quantify and merge the local indicators with scientific knowledge. Results indicated that farmers have their own indicators for soil erosion. Although most of these indicators can be explained scientifically, some were seasonal and site specific. Using farmers' indicators leads to early participation of farmers in problem identification, thus increasing their confidence and raising their awareness, in this case, on soil erosion as an indicator of soil quality.

1.6.3. Impact on CARE-Kenya, Kenya

In 2002, CARE-Kenya's Natural Resources Management Project, TASK (The Improved Agriculture for Smallholders in western Kenya) and the Jamaa Wazima Project used the methodological guide to train 34 farmers and extensionists from CARE and the Ministry of Agriculture on the concepts and methodological approaches to identifying and integrating local and scientific soil quality indicators. The training provided has contributed significantly to the mandate of the two projects in western Kenya with impacts at the institutional level of the project, as well as at farm level. Collaborators from the Ministry of Agriculture have since been able to use the guide in training farmers and fellow technicians on sustainable soil management strategies in other parts of western Kenya that include the Siaya, Busia and Homa Bay districts.

The training conducted with farmers enhanced their knowledge and practice on soil management for increased agricultural productivity, which is one of the important project objectives. Communication between farmers and extensionists for action planning and implementation of integrated soil management strategies was also improved. This is evidenced by an increased adoption of integrated soil fertility management strategies by trained farmers and an increase in farmers' capacity to make informed decisions on the type of interventions to employ depending on the degree of soil degradation. The training was a trust building exercise, which cemented farmer confidence in project-promoted technologies as relatively cheap and effective compared to the alternative of continuing soil degradation.

Among the impacts observed at the farmers' level was that trained farmers (especially those already adopting the technologies) were able to train other neighboring farmers on the use of soil quality indicators to diagnose soil constraints in order to develop relevant soil management strategies. With their training, farmers used the jointly developed local–technical soil quality indicators to identify early warning signs of degradation, which they then used to create broader awareness of the problem. These farmers were then able to successfully generate support in the larger community in formulating collective action plans that address community based integrated soil management strategies in Siaya, Busia and Homa Bay districts.

1.6.4. African feedback to Latin America

The adaptation process of the LISQ approach from Latin America to Africa consisted of two separate workshops conducted in Uganda and Tanzania. Both workshops contributed significantly to the realization of the considerable degree of commonality between local demands and problems faced by farmers in Africa and Latin America and hence the great potential to learn from each other. This experience is one step in facilitating that process by providing the methodological approaches and tools to improve communication between farmers and research/development professionals. The development and use of this methodological guide has been a good example of a full cycle of "South–South" cooperation where experiences from Latin America were brought and adapted to the African context, and feedback during adaptation process in Africa has helped further improvement of the Latin American guide. For example, in addition to revising the first four chapters, the fifth section on management options for overcoming soil management constraints identified during the LISQ and TISQ process was totally new to the east Africa version of the guide. This section was then adopted with the other changes in the new Latin America version.

2. Conclusions

Farmers need early warning indicators of soil quality and monitoring tools to guide soil management because the cost of preventing soil degradation is several times less than costs of remedial actions. Many technical solutions to soil degradation exist but are not adopted because they are developed without the participation of the land user or do not build on local knowledge about soil management. The methodology described here has generated positive impacts on the local knowledge base by providing a way for this tacit knowledge to be widely understood, assessed and utilized, and to be integrated with technical solutions. In addition, local communities have been empowered by the joint ownership of the "hybrid" knowledge base constructed during this process. Action plans developed by local actors through consensus building and new insights derived from the training exercise become the means by which profitable and resource conserving land management are locally promoted and widely adopted.

Farmers usually manage their soils for short-term maximization of benefits rather than with a longer-term perspective of soil resource use optimization. This means that they miss out on the longer-term benefits of ecosystem services. It is thus essential that farmers and other stakeholders in land management develop greater awareness about the livelihood and income generating opportunities that can be derived from the services provided by natural and agricultural ecosystems like provision of clean water, reduction in soil erosion, increased C sequestration and reduction of greenhouse gas emissions. However, in order for profits to be made from ecosystem services, a major change in sustainable natural resource management needs to occur, based on much wider adoption of improved land management options.

3. Uncited references

Beare et al., 1997
Woomer and Swift, 1994

Acknowledgements

The authors thank A. Hartemink, L. Brussaard and A. McBratney for constructive reviews of an earlier version of this manuscript. The financial support provided by the CGIAR Systemwide Program of Soils, Water and Nutrient Management (SWNM) for the development of the guide is gratefully acknowledged.

References

Altieri, M.A., 1990. Why study traditional agriculture? In: Carrol, C. R., Vandermeer, J.H., Rosset, P. (Eds.), Agroecology. McGraw-Hill, New York, N.Y., pp. 551–564.

Barrios, E., Trejo, M.T., 2003. Implications of local soil knowledge for integrated soil fertility management in Latin America. Geoderma 111, 217–231.

Barrios, E., Herrera, R., Valles, J.L., 1994. Tropical floodplain agroforestry systems in mid-Orinoco River basin, Venezuela. Agroforestry Systems 28, 143–157.

Barrios, E., Buresh, R.J., Sprent, J.I., 1996. Organic matter in soil particle size and density fractions from maize and legume cropping systems. Soil Biology & Biochemistry 28, 185–193.

Barrios, E., Kwesiga, F., Buresh, R.J., Sprent, J.I., 1997. Light fraction soil organic matter and available nitrogen following trees and maize. Soil Science Society of America Journal 61, 826–831.

Barrios, E., Bekunda, M., Delve, R.J., Esilaba, A., Mowo, J., 2001. Identifying and classifying local indicators of soil quality. Eastern Africa Version. Participatory Methods for Decision Making in Natural Resource Management. CIAT-SWNM-TSBF-AHI.

Beare, M.H., Cameron, K.C., Williams, P.H., Doscher, C., 1997. Soil quality monitoring for sustainable agriculture. Proceedings of the 50th New Zealand Plant Protection Conference. N.Z. Plant Protection Society, pp. 520–528.

Birang, M., Hauser, S., Amougou, D.L., 2003. Farmer's perceptions of the effects of earthworms on soil fertility and crop performance in southern Cameroon. Pedobiologia 47 (5/6), 819–824.

Brussaard, L., Kuyper, T.W., Didden, W.A.M., de Goede, R.G.M., Bloem, J., 2004. Biological soil quality from biomass to biodiversity—importance and resilience to management stress and disturbance. In: Schjonning, P., Elmholt, S., Christensen, B.T. (Eds.), Managing Soil Quality: Challenges in Modern Agriculture. CAB International, Wallingford, pp. 139–171.

Cook, S.E., Adams, M.L., Corner, R.J., 1998. On-farm experiments to determine site-specific response to variable inputs. In: Robert, P.C. (Ed.), Fourth International Conference on Precision Agriculture, St. Paul, Minnesota: ASA/CSSA/SSSA, ASPRS, PPI.

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

Doran, J.W., Jones, A.J. (Eds.), 1996. Methods for Assessing Soil QualitySoil Science Society of America Special Publication, vol. 49. Madison, Wisconsin.

Doran, J.W., Parkin, T.B., 1994. Defining and assessing soil quality. In: Doran, J.W., Coleman, D.C., Bezdicek, D.F., Stewart, B.A. (Eds.), Defining Soil Quality for a Sustainable Environment. Soil Science Society of America Special Publication, vol. 35, pp. 3–21. Madison, Wisconsin.

Foster, A.D., Rosenzweig, M.R., 1995. Learning by doing and learning from others: human capital and technical change in agriculture. Journal of Political Economy 103 (6), 1176–1209.

Hecht, S.B., 1990. Indigenous soil management in the Latin American tropics: neglected knowledge of native peoples. In: Altieri, M.A., Hecht, S.B. (Eds.), Agroecology and Small Farm Development. CRC Press, Boca Raton, Florida, pp. 151–157.

Isham, J., 2002. The effect of social capital on fertilizer adoption: evidence from rural Tanzania. Journal of African Economies 11 (1), 39–60.

Jenny, H., 1941. Factors of Soil Formation. McGraw-Hill Book Co., New York.

Jenny, H., 1980. The Soil Resource: Origin and Behavior. Springer-Verlag, New York.

Karlen, D.L., Mausbach, M.J., Doran, J.W., Cline, R.G., Harris, R.F., Schuman, G.E., 1997. Soil quality: concept, rationale, and research needs. Soil Science Society of America Journal 60, 4–10.

Knoepp, J.D., Coleman, D.C., Crossley Jr., D.A., Clark, J.S., 2000. Biological indices of soil quality: an ecosystem case study of their use. Forest Ecology and Management 138, 357–368.

Lal, R., Stewart, B.A., 1995. Soil Management: Experimental Basis for Sustainability and Environmental Quality. Advances in Soil ScienceCRC Press, Boca Raton, Florida.

Mairura, F.S., Mugendi, D.N., Mwanje, J.I., Ramisch, J.J., Mbugua, P. K., 2004. Scientific assessment of farmers' perceptions of soil quality indicators within smallholder farms in the central highlands of Kenya. In: Bationo, A., Kimetu, J., Kihara, J. (Eds.), International Symposium of the African Network for Soil Biology and Fertility (AFNET): Improving Human Welfare and

Environmental Conservation by Empowering Farmers to Combat Soil Fertility Degradation, Yaoundé, Cameroun, May 17–21, 2004.

Oberthur, T., Barrios, E., Cook, S., Usma, H., Escobar, G., 2004. Increasing the relevance of scientific information in hillside environments through understanding of local soil management in a small watershed of the Colombian Andes. Soil Use and Management 20, 23–31.

Oldeman, L.R., Van Lyden, G.W.J., 1998. Revisiting the Glasod methodology. In: Lal, R., Blum, W.H., Valentine, C., Stewart, B.A. (Eds.), Methods for Assessment of Soil Degradation. Advances in Soil Science. CRC Press, N.Y., pp. 423–458.

Pankhurst, C.E., Doube, B.M., Gupta, V.V.S.R., 1997. Biological Indicators of Soil Health. CAB International, Wallingford.

Pawluk, R.R., Sandor, J.A., Tabor, J.A., 1992. The role of indigenous soil knowledge in agricultural development. Journal of Soil and Water Conservation 47 (4), 298–302.

Pieri, C., Dumanski, J., Hamblin, A., Young, A., 1995. Land Quality Indicators. World Bank Discussion Paper, vol. 315. The World Bank, Washington, DC.

Pretty, J., Ward, H., 2001. Social capital and the environment. World Development 29 (2), 209–227.

Sánchez, P.A., 1994. Tropical soil fertility research: towards the second paradigm. 15th World Congress of Soil Science, vol. 1, pp. 65–88. Acapulco, Mexico.

Sandor, J.A., Furbee, L., 1996. Indigenous knowledge and classification of soils in the Andes of southern Peru. Soil Science Society of America Journal 60, 1502–1512.

Sarrantonio, M., Doran, J.W., Liebig, M.A., Halvorson, J.J., 1996. On-farm assessment of soil quality and health. In: Doran, J.W., Jones, A.J. (Eds.), Methods for Assessing Soil Quality. Soil Science Society of America Special Publication, vol. 49, pp. 83–105. Madison, Wisconsin.

Schjonning, P., Elmholt, S., Christensen, B.T. (Eds.), 2004. Managing Soil Quality: Challenges in Modern Agriculture. CAB International, Wallingford.

Schultz, T.W., 1964. Transforming Traditional Agriculture. Yale University Press, New Haven.

Swift, M.J., Woomer, P.L., 1993. Organic matter and the sustainability of agricultural systems: definition and measurement. In: Mulongoy, K., Merckx, R. (Eds.), Soil Organic Matter Dynamics and Sustainability in Tropical Agriculture. Wiley, UK, pp. 3–18.

Tenge, A.J., Ley, G.J., Hella, J.P., Mowo, J.G., 2002. Development of an improved method for soil and water conservation planning at the catchment scale in the East African Highlands. ROAHI Progress Report, Lushoto, Tanzania.

Trejo, M.T., Barrios, E., Turcios, W., Barreto, H., 1999. Método Participativo para identificar y clasificar Indicadores Locales de Calidad del Suelo a nivel de Microcuenca. Instrumentos Metodológicos para la Toma de Decisiones en el Manejo de los Recursos Naturales. CIAT-CIID-BID-COSUDE. .

TSBF-CIAT, 2005. Integrated Soil Fertility Management in the Tropics: From Knowledge to Implementation. Strategy and Workplan 2005–2010. .

Velasquez, E., 2004. Bioindicadores de Calidad de Suelo basados en las Comunidades de Macrofauna y su Relación con Características Funcionales del Suelo, PhD Thesis. Universidad Nacional de Colombia, Palmira.

Woomer, P.L., Swift, M.J. (Eds.), 1994. The Biological Management of Soil Fertility. John Wiley & Sons, New York.

Walker, D.H., Sinclair, F.L., Thapa, B., 1995. Incorporation of indigenous knowledge and perspectives in agroforestry development: Part I. Review of methods and their application. Agroforestry Systems 30, 235–248.

Warren, D.M., 1991. Using indigenous knowledge in agricultural development. Discussion Paper, vol. 127. The World Bank, Washington DC.

Winklerprins, A., 1999. Local soil knowledge: a tool for sustainable land management. Society and Natural Resources 12 (2), 151–161.

Winklerprins, A., Sandor, J.A., 2003. Local soil knowledge: insights, applications, and challenges. Geoderma 111, 165–170.