

## SCIENTIFIC EVALUATION OF SMALLHOLDER LAND USE KNOWLEDGE IN CENTRAL KENYA

F. S. MAIRURA<sup>1\*</sup>, D. N. MUGENDI<sup>2</sup>, J. I. MWANJE<sup>2</sup>, J. J. RAMISCH<sup>1</sup>, P. K. MBUGUA<sup>3</sup>  
AND J. N. CHIANU<sup>1</sup>

<sup>1</sup>*Tropical Soil Biology and Fertility, P.O. Box 30677, Nairobi*

<sup>2</sup>*Department of Environmental Resource Conservation, Kenyatta University, P.O. Box 43844, Nairobi*

<sup>3</sup>*Department of Botany, Kenyatta University, P.O. Box 43844, Nairobi*

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### ABSTRACT

The following study was conducted to determine smallholders' land use management practices and agricultural indicators of soil quality within farmers' fields in Chuka and Gachoka divisions in Kenya's Central Highlands. Data on cropping practices and soil indicators were collected from farmers through face-to-face interviews and field examinations. Farmers characterised their fields into high and low fertility plots, after which soils were geo-referenced and sampled at surface depth (0–20 cm) for subsequent physical and chemical analyses. Farmers' indicators for distinguishing productive and non-productive fields included crop yield, crop performance and weed species. Soils that were characterised as fertile, had significantly higher chemical characteristics than the fields that were of poor quality. Fertile soils had significantly higher pH, total organic carbon, exchangeable cations and available nitrogen. Factor analysis identified four main factors that explained 76 per cent of the total variance in soil quality. The factors were connected with farmers' soil assessment indicators and main soil processes that influenced soil quality in Central Kenya. Soil fertility and crop management practices that were investigated indicated that farmers understood and consequently utilised spatial heterogeneity and temporal variability in soil quality status within their farms to maintain and enhance agricultural productivity. Copyright © 2007 John Wiley & Sons, Ltd.

KEY WORDS: farmers; local indicators; local knowledge; scientists; soil quality; factor analysis; Kenya

### INTRODUCTION

Scientists and farmers are becoming increasingly concerned about the declining fertility of soils in the highlands of Eastern Africa and Sub-Saharan Africa (Sanchez and Leakey, 1997; Bationo, 2004). Due to continuous intensive cropping, farmers have experienced declining crop yields over time (Mugendi *et al.*, 1999), hence raising both scientific and farmer environmental concerns over land quality. Indeed there is a general agreement by both farmers and scientists across the world regarding agro-ecosystem performance, long-term yield patterns and soil quality. Land degradation and increasing soil quality variability is a severe problem in the densely populated highlands of Central Kenya, and elsewhere on the African continent (Murage *et al.*, 2000). Human-induced soil degradation has affected 65 per cent of Africa's arable soils (Sivakumar and Wills, 1995). The Central Highlands of Kenya are densely populated with more than 500 persons km<sup>-2</sup>, and small land sizes averaging 1.2 ha per household (Government of Kenya, 1997). The cultivation on steep slopes (up to 60 per cent) is a common practice in the area (Lekasi *et al.*, 2001). Soil erosion (resulting from cultivation on steeply sloping terrain) and mining of soil fertility (due to continuous cultivation with limited applications of inorganic or organic sources of soil nutrients) are among the key factors that have led to low agricultural productivity, widespread poverty and food insecurity in the region (Mugendi *et al.*, 1999).

\* Correspondence to: F. S. Mairura, Tropical Soil Biology and Fertility, P.O. Box 30677, Nairobi, Kenya.  
E-mail: fsmairura@yahoo.com

Land use management practices on smallholder farms inevitably determine soil fertility status and agricultural sustainability. Within farms, fields undergoing soil fertility decline lead to reduced productive land units as a result of nutrient losses. Large differences in nutrient balances can often be observed between fields and within a farm, resulting from substantial differences in soil fertility status between those fields (Vanlauwe *et al.*, 2002).

The on-farm mechanisms that lead to soil variability within fields in central Kenya smallhold farms have been well studied by soil scientists. Intensively managed smallholdings in Central Kenya typically contain three enterprise areas; namely, the 'outfields', 'infields' and 'home sites' (Woomer *et al.*, 1998). The 'outfields' constitute of cereal-legume intercrops intended for home consumption, while 'infields' are mainly constituted of market crops. 'Home sites' are used as livestock production sites and kitchen gardens. Due to livestock confinement in 'home sites', manures and composts are accumulated leading to the build-up of organic materials (Woomer *et al.*, 1998). Crop residues from the 'outfields' are typically harvested and fed to livestock while manures are applied to valued crops, especially those of the 'infields' intended for the market. The consistent nutrient 'mining' of 'outfields' results in nutrient deficient soils and crops (such as maize and beans that are grown in these sites) that are characteristic of most small-scale farms in Central Kenya (Murage *et al.*, 2000). Carsky *et al.* (1998) and Vanlauwe *et al.* (2002) found that fields close to the homestead had better soil fertility characteristics than fields that were remotely placed and far from the homestead. Additionally, Vanlauwe *et al.* (2002) found that maize yield was significantly related to initial total soil nitrogen in Western Kenya, showing the effect of soil fertility gradients on crop productivity. Crop growth characteristics for crops such as maize are very sensitive to differences in soil fertility (Jensen and Cavalieri, 1983) and this is often used by farmers to differentiate inherent soil fertility status (Maddoni *et al.*, 1999).

Small-scale farmers around the world have cultivated agroecosystems sustainably based on the knowledge they have accumulated through local farming practices (Pulido and Bocco, 2003). Cultivation by indigenous farmers was sustainable because it allowed for adequate restoration of soil fertility during the fallowing phase (Padwick, 1983). Sustainability in this study refers to the ability to cultivate soils productively, without causing irreversible damage to ecosystem health (Altieri, 1995).

Spatial variability in soil fertility resulting from farm-level decisions regarding soil management can be characterised by indicators utilised by farmers and scientists. This was shown by Tittonell *et al.* (2005) who observed that soil fertility indicators and nutrient concentrations varied quite consistently between different land quality classes according to farmers' criteria in Western Kenya. Local soil indicators and indicator plants have not been fully evaluated in most smallhold farming systems, yet a scientific assessment of farmers' soil knowledge is needed to enable sustainable land management by scientists and farmers. The use of plant indicators to characterise soils by farmers is an important visual criteria, however, the local knowledge of plant species has not been well documented (Nandwa and Bekunda, 1998). Until recently, scientists underestimated farmers' knowledge on soil fertility and management (Richards, 1985; Fairhead, 1992; Nandwa and Bekunda, 1998). Indeed, local knowledge systems are not sufficiently integrated in formal literature. Research on specific thematic areas of farmers' soil knowledge, such as soil biological processes is lacking. Grossman (2003) pointed out that papers that document the effect of management practices on the soil biological community lack research describing the farmers' knowledge base on which management decisions were made. Because of soils' importance, an assessment of soil quality is needed to determine the sustainability of land management systems as related to agricultural production practices, and to assist farmers and scientists in formulating and evaluating agricultural land use systems. To make an interpretation and holistic evaluation, soil quality cannot be measured directly, but must be inferred from soil quality indicators and visual assessments of farmers and soil scientists. Many soil properties are correlated (Larson and Pierce, 1994), and must therefore be evaluated by statistical procedures that account for multivariate correlation among soil attributes. A comprehensive assessment of how farming communities recognise and measure soil quality is needed so that indigenous knowledge can be integrated with scientific knowledge to contribute to soil quality information (Doran and Parkin, 1994).

This study evaluated farmers' soil fertility knowledge and common management practices by relating soil measurements with soil quality indicators identified by farmers in Kenyas' Central Highlands. The study was undertaken, to identify indicators of soil quality status that were consistent with farmers' perceptions of soil quality

and to determine the influence of common management practices on soil fertility status. As specific concepts, 'soil fertility' and 'soil quality' are used in congruence and in similar manner with Patzel *et al.* (2000).

## MATERIALS AND METHODS

### *Site Description and Characteristics*

The study was conducted in two agricultural districts of Central Kenya Highlands, located approximately 150 km NE of Nairobi, Kenya. Sixty farms were sampled within village enclaves of Kirege and Gachoka sub-locations in Chuka and Gachoka divisions, respectively. Consequently the sample size of the respondents was 60. Chuka Division lies in the Upper Midland zone 2 and 3 (UM2 and UM3) at an altitude of 1500 m, with an annual rainfall ranging from 1200–1400 mm (Jaetzold and Schmidt, 1983). The soil type is mainly Humic Nitisol with those in Gachoka being dominated by the Nito-rhodic Ferralsols (Jaetzold and Schmidt, 1983). Chuka is dominated by slope cultivation (up to 60 per cent) and crop-livestock enterprises that are intensively managed (Warner, 1993; Lekasi *et al.*, 2001). Gachoka division lies at the transition between the marginal cotton (LM 4) and main cotton (LM3) agro-ecological zones (Jaetzold and Schmidt, 1983) with a mean annual rainfall of 900 mm (Government of Kenya, 1997). Rainfall distribution pattern is bimodal, in both divisions with the short rain (SR) and long rain (LR) season falling annually from March to June and October to December, respectively (Jaetzold and Schmidt, 1983).

### *Household Interviews and Field Observations*

Farms were randomly selected in Chuka and Gachoka Divisions, respectively, following soil fertility replenishment programmes that were started by the Rockefeller Foundation in 2003. The study sites were selected after initial field visits, workshops, and field schools were conducted in the area by the Rockefeller project. During the start of the study, a list of villages was obtained from divisional offices in Chuka and Gachoka divisions to constitute the sampling frame, from which a total of 30 farm households were randomly selected in each of the divisions prior to visiting farmers in their fields. As a result, a total of 60 farmers were sampled in both divisions. In Chuka division, 15 males and 15 females were selected, while in Gachoka division, 21 females and nine males were selected for the study.

The survey was conducted within the months of February and October in 2003, using questionnaires. First, field instruments were pretested in a pilot study that was conducted in the dry season, while the main study was conducted during the rainy season in the months of March to June. Data were collected in the LR season, so as to capture weed species diversity and to enable wet soil sampling. During the survey, farmers were asked to identify plots that were regarded as productive (good quality) or non-productive (poor quality). High and low fertility plots were designated by the farmers themselves, prior to soil sampling using crop and soil indicators that they had identified themselves. The researchers did not select fertile or infertile fields. Soil fertility indicators including weed species associated with high and low productive soils were also identified by farmers and recorded. Plant indicator data were recorded as presence-absence data following (Suarez *et al.*, 2001). The indicator weeds specimens were collected then pressed to preserve them, until they were identified with the technical involvement of a botanist from Kenyatta University.

### *Soil Sampling and Analysis*

Soil sampling was done on fertile and infertile fields that had been characterised by farmers using their own descriptive indicators (Gachimbi *et al.*, 2002). Soils were sampled by compositing ten topsoil (0–20 cm depth) samples per field, after which sub-samples (500 g) were sealed and transported in cool boxes and refrigerated in a cold room at 4°C (Anderson and Ingram, 1993). The soil analysis commenced in the laboratory approximately 1 week after sampling. Soil parameters that were analysed included texture, pH, exchangeable calcium, exchangeable magnesium, available nitrogen, available phosphorous, soil organic carbon, total nitrogen and total phosphorous.

Soil texture was determined using the Bouyoucos Hydrometer method following Gee and Bauder (1986). Soil pH was determined by water extraction in a 1:2.5 ratio. Exchangeable bases (calcium and magnesium) were extracted in 1M KCl, followed by colorimetric and titrimetric determination, respectively. For available phosphorous extraction, a 0.5M NaHCO<sub>3</sub> + 0.001M EDTA, pH 8.5 solution was used, followed by colorimetric determination. Ammonium-N

was determined by the salicylate-hypochlorite colorimetric method, while Nitrate-N was determined by the cadmium-reduction method. Total organic carbon was determined through colorimetric determination of released chromic ions ( $\text{Cr}^{3+}$ ) after soils were digested in acidified dichromate at  $130^{\circ}\text{C}$  for 30 minutes. Total nitrogen and total phosphorous were determined using the Kjeldhal Digestion method (Anderson and Ingram, 1993).

### Data Analysis

Social data were analysed using SPSS version 11<sup>®</sup> (SPSS, 2002), while soil measurements were entered in Genstat. Soil parameters were compared by Analysis of variance (ANOVA) in Genstat 5 Release 3<sup>®</sup> (Genstat, 1995), whereby the soil quality categories were the grouping variables (Wardle, 1994). Means for soil properties were compared using Standard Error of the Difference (SEDs). Prior to running factor analysis, the soil dataset was log-transformed to normalise the data (SPSS, 2002). Factor analysis was used to study the relationship among soil variables, by statistically grouping 11 soil attributes into 4 factors (Brejda *et al.*, 2000) through the Varimax rotation procedure. Varimax rotation with Kaiser normalisation was used because it results in a factor pattern that loads highly into one factor, which was considered to offer a theoretically plausible and suitable interpretation of the resulting factors.

## RESULTS AND DISCUSSION

### Farmers' Characteristics

Table I shows the general characteristics of farmers and the farming system in Central Kenya. There were 15 (50 per cent) male and 15 (50 per cent) female farmers in Chuka division, while in Gachoka, females constituted 70 per cent

Table I. Characteristics of households and cropping systems in Chuka and Gachoka divisions

Parameters	Division		Significance
	Chuka	Gachoka	
Gender			
Female	15 (50)	21 (70)	
Male	15 (50)	9 (30)	
Education level			
None	2 (6.7)	5 (16.7)	
Primary	15 (50)	16 (53)	
Secondary	10 (33.3)	9 (30)	
Post secondary	3 (10)	0 (0)	
Land tenure			
Owner	19 (63.3)	22 (73.3)	
Inherited	11 (36.7)	4 (13.3)	
Purchased	0 (0)	4 (13.3)	
Farm characteristics			
Farm size (ha)	1.1	4.4	**
Years since farm was cultivated	18.5	21.9	NS
Number of household members	6.5	6.9	NS
Percentage of farm that is flat	21.3	44.3	*
Percentage of farm that is steep	30.7	11.0	*
Number of cattle kept	1.8	4.7	**
Farmers using fertilisers	27 (90)	24 (80)	
Soil management practices			
Farmers using hybrid seeds	19 (63)	11 (37)	
Farmers keeping livestock	29 (97)	27 (90)	
Farmers using cattle manure	28 (93)	26 (87)	

Values in parenthesis are percentages.

\*Significant at 0.001 level, \*\* Significant at 0.05 level, NS, probability values that are not significant.

of the sample (Table I). Educational attainment was slightly better in Chuka division than in Gachoka division because there were more farmers in Chuka than in Gachoka who had attained secondary education, also, more farmers in Gachoka had no education compared to those in Chuka. Farm sizes and the number of livestock kept were both significantly more in Gachoka than in Chuka division, but farmers in Gachoka kept local livestock varieties that were free grazed, compared to livestock hybrid varieties in Chuka division that were mainly restricted and pen-fed or fed in the homestead.

#### *Descriptive Soil Indicators*

The most frequent agricultural indicators that were used by farmers to characterise soil fertility included crop yield and crop performance which were reported by more than 60 per cent of the farmers in both divisions (Table II). Other indicators included soil colour, soil texture and agricultural weed species. Usually, plots within fields were characterised as either fertile or infertile, with indicators described dichotomously as either good or bad, or high or low. The least common indicators included soil texture, fertiliser response and soil moisture retention which were identified by less than 40 per cent of the farmers. Soil indicators were significantly associated with district. Table II shows the soil quality indicators utilised by farmers in both divisions.

#### *Soil Fertility Indicator Weed Species*

Farmers used several weed species as land quality indicators to differentiate soil fertility status on their fields. The high and low fertility indicator species are shown in Table III. The most frequent high fertility indicator species was *Commelina benghalensis* L. in Chuka division while in Gachoka division it was the black jack (*Bidens pilosa* L.) (Table III). Conversely, the most frequent low fertility indicator weed species in Chuka division (*Melhanio ovata* (Cav.) Spreng) was recorded on 67 per cent of the fields, with a higher frequency for Gachoka division (93 per cent) (Table III).

Other indicators that were recorded on productive fields included the gallant soldier (*Galinsoga parviflora* L.) and *Amaranthus* spp. (Table III). Additionally, less frequent low fertility species included the goat weed (*Ageratum conyzoides* L.). The red top grass (*Rhynchelytrum repens* (Willd., C. E. Hubbard) which was more frequent in Gachoka (70 per cent) compared to Chuka (27 per cent), was cited by farmers as a low fertility indicator (Table III). In both divisions farmers admitted that there was a high diversity of species on productive soils as compared to poor soils.

#### *Soil Fertility Management Practices and Crop Distribution*

Different crops were cultivated in productive and non-productive fields, though some such as maize were grown on both high and low fertility soils (Figure 1). Major cropping enterprises included maize (*Zea mays* L.) and beans (*Phaseolus vulgaris* L.) in both divisions, which were mainly cultivated on the fertile fields. Tuber crops such as

Table II. Descriptive indicators used by farmers to distinguish soil quality status within fields in Chuka and Gachoka divisions, Kenya

Chuka division		Gachoka division		
Indicator	% Farmers	Indicator	% Farmers	$\chi^2$ probability
Crop yield	86 (26)	Crop yield	67 (20)	0.000
Crop performance	77 (23)	Crop performance	63 (19)	0.000
Soil colour (wet)	60 (18)	Soil colour (wet)	83 (25)	0.003
Soil macro-fauna	50 (15)	Soil macro-fauna	37 (11)	0.000
Soil tilth	40 (12)	Soil tilth	40 (12)	0.027
Soil texture	40 (12)	Soil texture	43 (13)	0.000
Fertiliser response	13 (4)	Fertiliser response	20 (6)	0.000
Soil moisture retention	3 (1)	Soil moisture retention	7 (2)	0.000

Values in parentheses are number of farmers.

Table III. Weed species used by farmers to indicate high and low soil fertility status in Chuka and Gachoka divisions, Kenya

Scientific name	Indicator species		Percentage frequency	
	Common name	Botanical family	Chuka	Gachoka
High fertility indicator species				
<i>Commelina benghalensis</i> L.	Wandering jew	Commelinaceae	77 (23)	53 (16)
<i>Galinsoga parviflora</i> L.	Gallant soldier	Compositae	63 (19)	17 (5)
<i>Bidens pilosa</i> L.	Black jack	Compositae	43 (13)	67 (20)
<i>Amaranthus</i> spp.	Pigweed	Amaranthaceae	20 (9)	27 (8)
<i>Sonchus oleraceus</i> L.	Sow thistle	Compositae	17 (5)	13 (4)
<i>Commelina diffusa</i> Burm.f.	—	Commelinaceae	9 (30)	53 (16)
<i>Solanum nigrum</i> L.	Black nightshade	Solanaceae	7 (2)	20 (6)
<i>Rottboellia exaltata</i> (L.f)	Guinea fowl grass	Gramminae	7 (2)	7 (2)
Low fertility indicator species				
<i>Melhania ovata</i> (Cav.) Spreng	—	Malvaceae	67 (20)	93 (28)
<i>Ageratum conyzoides</i> L.	Goat weed	Compositae	37 (11)	10 (3)
<i>Emilia discifolia</i> (Oliv.) C. Jeffrey	—	Compositae	37 (11)	3 (1)
<i>Rhynchelytrum repens</i> (Wild.) C. E. Hubbard	Red top grass	Gramminae	27 (8)	70 (21)
<i>Pteridium aquilinum</i> (L.) Kuhn	Bracken fern	Pteridophyte	27 (8)	14 (4)
<i>Tagetes minuta</i> L.	Mexican marigold	Compositae	16 (5)	23 (7)
<i>Oxygonum sinuatum</i> (Meisn.) Dammer	Double thorn	Polygonaceae	10 (3)	3 (1)
<i>Schkuhria pinnata</i> (Lam.) Thell.	Dwarf marigold	Compositae	3 (1)	10 (3)
<i>Setaria verticillata</i> (L.) Beav.	Bristly foxtail	Gramminae	—	23 (7)
<i>Cucumis</i> L.	—	Cucumbitaceae	—	20 (6)

Values in parentheses are number of farmers.

cassava (*Manihot esculenta* L.), sweet potatoes (*Ipomea batatas* L.) and fodder grasses mainly occurred on poor fields in both divisions. Farmers planted food crops with a high staple and economic value on fertile fields, while fodder crops or low value crops were predominantly cultivated on poor fields.

#### Soil Physical and Chemical Properties

Tables IV and V present measured physical and chemical soil properties in the two sub-locations, respectively.

Soil texture distribution was almost similar within soil fertility categories in both divisions, with no significant differences in sand, clay and silt distribution (Table IV). Clay and sand distribution was lower in high fertility sites than low fertility sites in both divisions. Silt was slightly higher in the fertile fields in Chuka division compared to the poor fields.

The productive soils showed higher soil carbon ( $p < 0.05$ ) and exchangeable cations than infertile soils in both divisions (Table V). In Gachoka, low fertility carbon was lower than the fertile plot mean. Exchangeable calcium ( $p < 0.001$ ) was only significant in Gachoka division, while exchangeable magnesium was higher ( $p < 0.05$ ) in fertile sites in both divisions. Soil reaction (pH) was also higher in both divisions ( $p < 0.001$ ) on fields that farmers had identified as fertile, while extractable inorganic nitrogen was different ( $p < 0.05$ ) in Gachoka.

There were no differences in total phosphorous and total nitrogen in both divisions suggesting that they were not sensitive indicators of soil quality. Total nitrogen in Chuka division averaged 0.16 per cent (Table V) in both farmer soil category types. Available P indicated that soils in Chuka division had a higher capacity to supply P for crop growth, although this difference was not significant. However, 20 of the 30 pairs within fields matched consistently with the soil categories that farmers had ascribed.

#### Soil Variability and Factor Analysis

Table VI shows the factor analysis for measured soil properties, explaining the amount of variability accounted for by various soil factors. Eleven soil attributes were reduced by factor analysis to four main soil factors. The first four factors explained 76 per cent of the variance (Table VI), and contained eigen values that were greater than 1

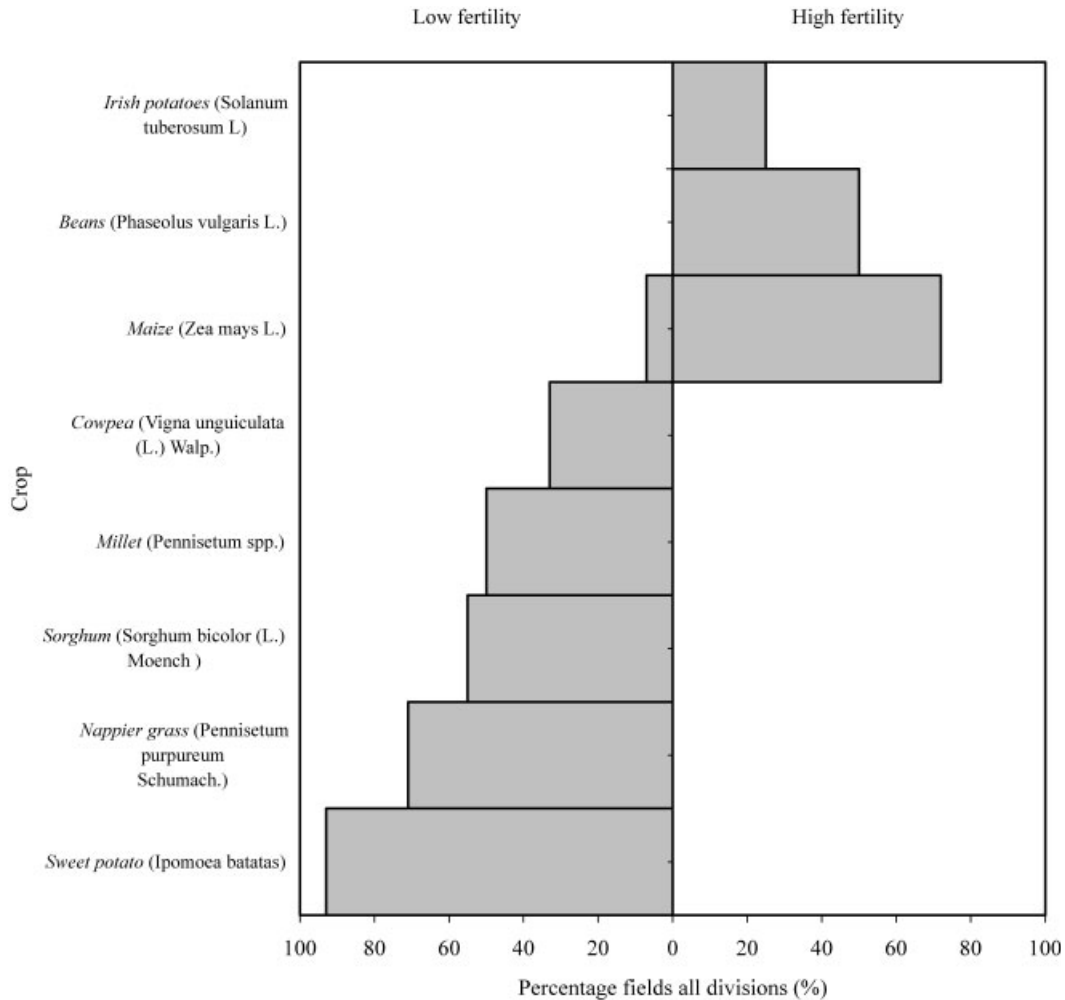


Figure 1. The distribution of crops on fertile and infertile soils in Chuka and Gachoka divisions.

(Table VI). The KMO measure of sampling adequacy (0.552) was satisfactory for factor analysis, while the Bartlett's test of sphericity was significant ( $p = 0.000$ ), implying that the correlation matrix was not an identity matrix (SPSS, 2002).

The four reduced factors were consequently retained for identification and interpretation (Brejda *et al.*, 2000). The factors were designated as contrasts, or soil processes that influenced land quality in farmers' fields. Large

Table IV. Soil physical properties on high and low fertility sites on farmers' fields in Chuka and Gachoka divisions

Site	Farmer soil category	Clay (%)	Sand (%)	Silt (%)	
Chuka	High	32.9	37.9	29.2	
	Low	34.5	38.0	27.5	
Gachoka	SED		3.7	5.0	
		High	30.3	67.1	2.7
	SED	Low	32.9	64.0	3.1
			5.5	3.2	5.0

Table V. Soil chemical properties from high and low fertility sites in Chuka and Gachoka divisions

Soil quality category	Total N (%)	Total P (%)	C (mg kg <sup>-1</sup> )	N (mg kg <sup>-1</sup> )	P (mg kg <sup>-1</sup> )	Ca (cmol <sub>c</sub> kg <sup>-1</sup> )	Mg (cmol <sub>c</sub> kg <sup>-1</sup> )	pH
Chuka								
High	0.16a	0.05a	33.6a	2.74a	20.5a	8.2a	3.1a	5.6a
Low	0.16a	0.05a	24.3b	2.79a	16.0a	7.5a	2.8b	5.1b
SED	0.02	0.01	3.99	0.16	4.27	0.65	0.12	0.08
Gachoka								
High	0.16a	0.05a	15.2a	2.43a	17.8a	5.8a	1.8a	6.5a
Low	0.02a	0.05a	12.5b	1.40b	6.2a	3.8b	1.3b	6.4b
SED	0.18	0.01	0.18	0.21	7.27	0.48	0.15	0.09

Means followed by different letters in the same column are significantly different.

amounts of correlations (loadings) between nutrients and factors were used to identify the factors (Brejda *et al.*, 2000). Soil attributes that loaded values greater than  $\pm 0.3$  were used to group and identify soil factors (Brejda *et al.*, 2000).

The first factor was identified as the 'exchangeable bases and soil acidity factor' due to high positive loading on soil cations (Table VI). The factor is mainly linked to the soil cation exchange capacity (CEC). The second factor was identified as the 'organic matter factor', because its strong loadings were comprised mainly of soil organic resources (soil organic carbon). Factor 3 was identified as the 'nitrogen-phosphorous factor' due to positive loadings on extractable phosphorous and available nitrogen. The fourth factor was identified as the 'soil physical factor'. The extracted factors also explained 60–98 per cent of the variance in physical and chemical properties as indicated by the magnitude of their communalities (Table VI).

## DISCUSSION

### *Dissemination of Results to Farmers*

After the end of the study, results were disseminated back to farmers through field days and seminars. Farmers were also trained on how to recognise soil differences through recognition of crop deficiencies, and how to interpret soil

Table VI. Factor loadings and communalities for a four factor model of soil physical and chemical properties in Central Kenya

Parameter	Factor				Communalities	(% Variance
	1	2	3	4		
Exchangeable magnesium	0.897	0.037	-0.003	-0.007	0.656	35.8
Silt	0.800	-0.006	0.024	-0.401	0.807	17.9
Sand	-0.800	0.123	0.315	-0.121	0.643	12.3
Exchangeable calcium	0.782	0.135	-0.097	-0.133	0.6	10.4
Soil pH	-0.722	0.242	0.249	-0.027	0.795	6.5
Available nitrogen	0.627	0.228	0.406	0.345	0.729	6.0
Soil carbon	0.541	-0.389	0.370	0.135	0.983	4.0
Total phosphorous	0.105	0.897	-0.236	-0.043	0.769	3.6
Total nitrogen	0.083	0.835	-0.210	0.006	0.802	2.0
Available phosphorous	0.100	0.381	0.646	0.473	0.749	0.97
Clay	-0.023	-0.177	-0.605	0.765	0.873	0.31
Cummulative variance (%)	36	54	66	76		
Eigen values	3.933	1.974	1.356	1.142		

Kaiser-Meyer-Olkin (KMO) measure of sampling adequacy = 0.552.  
Bartlett's Test of Sphericity: ( $\chi^2 = 386.33$ , significance = 0.000).

differences in texture, moisture holding capacity and indicator species. Farmers were also trained on suitable cropping options and soil management practices for different soils on their fields and in demonstration farms.

### *Local Soil Knowledge*

Farmers used characteristics that they could see, feel or smell in their fields, based on historic experiences in cultivating their fields, and they readily recognised that soil quality affected crop performance and yield. Interviews and group discussions by Ali (2003) in Bangladesh indicated that farmers were knowledgeable of soil—crop association and crop suitability. Visual crop characteristics such as crop yield and crop vigour are easily assessed by farmers, and their evaluation by soil scientists find them highly responsive to soil fertility parameters. The utilisation of visual land quality indicators presents a rapid and efficient manner of appraising land management. Despite descriptive soil indicators, farmers identified weed species that are commonly used in visual assessments of soil quality. Soil scientists have advocated that local knowledge is useful to determine soils' relative productivity, which is increasingly viewed as an important component for better soil management (Pawluk *et al.*, 1992). Case studies have shown that there is a consistent rational basis to the use of local indicators of soil quality and their relation to improved soil management (Barrios and Trejo, 2003). The dominance of soil texture and soil colour as a differentiating characteristic is common in farmer soil knowledge, which has been shown in some studies to tally formal soil classifications in ethnopedological studies (Talawar and Rhoades, 1997).

### *Weed Indicator Species*

Farmers' reported a significant diversity of weeds on fertile plots which is consistent with productive soil being characterised by high species diversity (Mäder *et al.*, 2002). Within natural vegetation, there are some species that are adapted to high soil fertility (ruderal species) (Marschnev, 1995). Earlier workers (e.g. Grove, 1989) recognised the potential of vegetation in characterisation of agricultural landscapes, regarding some soil characteristics, such as salinity, available nutrients, physical structure and capacity for crop yield. Plant species diversity and composition have also been used as indicators for assessing ecological restoration in amended soils (Pastorok *et al.*, 1997). In the Orinoco floodplains (Latin America), farmers make a first selection of cropping fields based on the type of vegetation growing on the soil (Barrios and Trejo, 2003), by using associations of native plants as indicators of good and poor soils. In Sub-Saharan Africa, Shaxson (1997) found farmers in many countries closely relating soil quality with the nature and condition of vegetation, both native and planted. Consistent with this work, some of the indicator species that were utilised by most smallholder farmers in both divisions were found to be related to those reported by Murage *et al.* (2000) in Central Kenya highlands, and Barrios and Trejo (2003) in Latin America. In this study, farmers were able to associate 'exhausted' soils with invading grasses (gramminae), and succulent species with fertile soils as was reported by Barrios and Trejo (2003) with Andean hillside farmers in Colombia. Farmers reported that the red top grass appears after long-term cultivation that has resulted in infertile and compacted soils. Species composition from Commelinaceae and compositae weed families were frequent as high fertility indicators in up to 50 per cent of the agricultural land in both divisions. The Wandering Jew (*Commelina benghalensis* L.) and gallant soldier (*Gallinsoga parviflora* L.) were found to be frequent in high fertility fields as was reported in Central Kenya by Murage *et al.* (2000). The reports by farmers for *C. benghalensis* L. weed as a good fertility indicator agrees with Barrios *et al.* (2000). Globally, small-scale farmers have been reported to associate the nature and condition of vegetation, both native and planted with the level of field soil fertility (Shaxson, 1997).

Soil scientists have pointed out plant species as desirable indicators in agroecosystems (Suarez *et al.*, 2001). Barrios and Trejo (2003) indicated that native plants were important soil indicators that could be associated with modifiable soil properties. Maddoni *et al.* (1999) discussed soil—crop indicators thus creating a technical relationship between land quality and weed indicators. In relation to soil quality variability, Suarez *et al.* (2001) found that differences in soil management had resulted in differences in the composition of weed communities under small-scale farming conditions in Latin America. The increase in low indicator fertility species can thus be

utilised as a means to stimulate land use interventions needed to avert soil degradation. The use of indicator plants, belonging to local knowledge systems, when related to management actions could ease adoption of improved soil technologies (Barrios and Trejo, 2003).

Natural and agricultural ecosystems respond simultaneously to degradation and regeneration processes through natural succession (Barrios *et al.*, 2000). During these processes, the best adapted plants gradually replace those least adapted through a selection process that is exerted by climatic factors, nutrient deposition and changes in soil characteristics. In farming systems such changes in agricultural weeds have been shown to result from many factors, including differences in soil fertility (Suarez *et al.*, 2001). Farmers collect observations about changes in plant populations generated by changes in soil quality, a process which leads to the development of local knowledge systems. Systematically monitoring changes in diversity and abundance of weeds while observing changes in soil properties permits the establishment of a practical relationship between local and technical indicators of soil quality (Barrios *et al.*, 2000). There are, however, major research questions that need to be addressed regarding the relationship between soil and plant indicators. Despite the importance of plant/soil interactions, most recent ethnopedological reports focus on soil classification (Sandor and Furbee, 1996), and physical processes like erosion and water management (Hagmann *et al.*, 1997). There are no studies that consider soil characteristics that are difficult for farmers to see such as below-ground soil processes (WinklerPrins, 1999; Sherwood and Uphoff, 2000). Grossman (2003) concluded that farmers in Mexico possessed knowledge gaps regarding unobservable ecosystem processes, despite the fact that they had attended training. Suarez *et al.* (2001) related soil fertility status and vegetation indicators in Latin America, but such studies have not been well undertaken in Africa. While it is possible to relate crop characteristics such as maize and soil characteristics (Maddoni *et al.*, 1999; Vanlauwe *et al.*, 2002), studies are needed to verify the relationship between soil changes and weed indicator incidence that results from major soil fertility practices in agricultural landscapes.

#### *Soil–Crop Management Practices and Soil Quality*

Under increasing population density and land pressure, few farmers have the opportunities to fallow their land long enough to maintain soil fertility at sustainable levels. Farmers also use less fertiliser than those recommended by national programmes (Cheruiyot *et al.*, 2001). Also, labour and resource constraints mean that available inputs are utilised on selected sites due to labour and resource constraints (Vanlauwe and Giller, 2006). To manage soil fertility, organic resources and fertilisers were usually patchily applied within fields based on local perceptions of soil quality (Mairura *et al.*, 2003). This is indicated by differences in soil mean properties in the high and low fertility plots that were analysed. Sweet potato protects soil from erosion as a cover crop and napier grass is an indigenous plant that was used for soil regeneration by native farmers prior to European contact (Murage *et al.*, 2000). This helps to explain why the crops were mainly planted on poor soils. Besides, sweet potatoes, cassava and cowpeas are crops that farmers recognised as having productive potential in poor soils.

Routine agricultural practices, including rotation, planting, tillage and fertiliser application can encourage soil quality variation in the field (Gotway and Hergert, 1997). Research in Zimbabwe (Carter and Murwira, 1995) demonstrated how crop choice and field uses of organic and inorganic fertilisers are deliberately varied in accordance with small-scale variations in soil fertility conditions. In Zimbabwe (Carter and Murwira, 1995) as well as in Central Kenya (Murage *et al.*, 2000), farmers utilised spatial heterogeneity in soil fertility status within their fields as a means to maintain or enhance agricultural productivity, but crop choice and management also considers several agro-ecological and socio-economic factors.

#### *Soil Physical and Chemical Properties*

Mean clay and sand contents were almost similar on soil categories suggesting that the test sites were of similar soil categories (Jaetzold and Schmidt, 1983), implying that the differences in chemical properties must have resulted from past soil management (Murage *et al.*, 2000). Thus, the soils could be evaluated comparably (Karlen *et al.*, 1997). Silt was slightly lower in poor sites in Chuka division, especially on sites that farmers had identified soil

erosion as the main constraint to crop production. This finding is consistent with the principle that silt is usually the first mineral component of the soil to be detached in water erosion processes (Brady, 1984).

Soil cations were low in poor soils in both divisions, as compared to the fertile soils, mainly due to higher organic matter content on fertile sites (Hoffmann *et al.*, 2001). The fertile soils reflected a higher capacity to hold nutrients than the non-productive soils in both divisions, due to higher exchangeable cations in the fertile soils. Because exchangeable bases and pH are mainly influenced by soil organic matter (SOM), and the clay types and quantities were similar in poor and fertile soils, the differences in Ca, Mg and soil reaction (pH) are likely to have been caused by differences in soil organic carbon (Brady, 1984; Hoffmann *et al.*, 2001; Gachene and Kimaru, 2003). Cropping intensity affects the amount of magnesium that is available in soil. Poorly managed fields that were more susceptible to erosion may have led to faster losses of calcium and magnesium through leaching, hence the lower value in poor sites.

The higher amount of readily available P in fertile soils may partly reflect higher fertilisation associated with preferential use of soil inputs on fertile soils and valued crops (Schjønning *et al.*, 2002). In fertile soils, farmers predominantly grew valued crops intended for market and these sites were also associated with animal sheds, where manure accumulated, thus encouraging soil C build-up. Conversely, planting of fodder grasses and lack of soil amendment characterised the poor fields. Rather than to attempt to ameliorate fields undergoing degradation, farmers invested fertilisers and valued crops on fields that were fertile, leading to accumulation of soil nutrients on productive sites as compared to the poor sites. The consistent nutrient mining from poor fields eventually leads to portions of the farm exhibiting nutrient-deficiencies (Murage *et al.*, 2000).

Elsewhere, several studies have compared farmers' knowledge through soil analysis of good and poor fields. Liebig and Doran (1999) compared farmers' soil knowledge along established assessment protocols. Twenty-four conventional and organic farmers in eastern Nebraska, USA, were paired within regions based on similar agroclimates and soils, and their soil perceptions of conditions for 'good' and 'problem' soils on their farms were queried using a written questionnaire. Their perceptions of soil quality indicators tended to match the scientific assessment for 'good' soils and 'problem' soils. Farmers' perceptions were consistent for up to 75 per cent of the time for the majority of indicators evaluated in the study, indicating a high correlation between farmer criteria and scientific assessment. Arshad and Coen (1992) found that many soil attributes can be estimated by calibrating qualitative observations against measured values, in tandem with Halvorson *et al.* (1996) and Kundiri *et al.* (1997). These workers therefore recommended that qualitative knowledge should be an integral part of soil quality information.

### *Soil Factors and Soil Quality Variability*

Based on the soil attributes that comprised them, all components in the four factor model (Table VI) contribute to one or more of the soil quality factors proposed by Larson and Pierce (1994). The 'exchangeable bases and soil acidity factor' contributes to the ability of the soil to supply nutrients and sustain root growth. This factor was important explaining 35 per cent of the variance, and was frequently expressed by farmers in various crop growth characteristics as indicators of soil quality. The 'organic matter' and 'physical' factors contribute to the ability of the soil to accept, hold and release soil water and nutrients, and to respond to management and resist degradation (Larson and Pierce, 1994). This factor explained 18 per cent of the total variance in soil quality. The 'nitrogen-phosphorous' factor is important in supplying nutrients to plants especially P, and promoting root growth (Brejda *et al.*, 2000). This factor was frequently expressed by farmers in various crop growth characteristics, explaining 12 per cent of the soil variance, while the 'physical factor' accounted for 10 per cent of the variance. This implies that exchangeable cations differed most spatially among soil nutrients. Exchangeable bases vary more than other soil elements due to soil management, including cropping and fertiliser practices (Arnon, 1992; Kanwar, 1975).

Additionally, the losses due to cation leaching are usually very high, and mainly influenced by soil texture, and management regimes including cropping and fertiliser uses as reported by Kanwar (1975). SOM is important in maintaining soil structure and releasing plant nutrients in the soil. SOM is also one of two sources of CEC in the

soil. CEC represents the sites in the soil that can hold positively charged nutrients like calcium, magnesium and potassium. CEC is dependent upon the amount of organic matter and clay in soils and on the types of clay. In general, the higher OM and clay content, the higher the CEC (Brady, 1984).

In Central Kenya, where farming is characterised by intensive cultivation and competing agricultural enterprises, the use of fertilisers and carbon inputs is maximised on preferred fields (high fertility sites) and crops. Factor analysis of the soil properties (Table VI) imply that soil cation exchange, soil reaction and nutrient availability may be key processes influencing soil quality in Central Kenya.

## CONCLUSION

Regarding relationships between the descriptive indicators and measured properties, there were clear differences in crop yield, crop performance, soil colour, tilth, fertiliser response and moisture retention in the high and low fertility fields identified by farmers. In infertile fields, crops were found to be stunted in growth while fertile fields produced good crop vigour and high yields, due to differences in soil nutrients. Fertile soils were indicated by darker colour, better tilth, better crop response to fertilisers and soil moisture retention. The results indicate that there were significant differences among soil fertility categories for key soil properties, suggesting that there was a difference in the soils that were characterised as different by farmers. These findings are important because they form an entry point for closer examination of farmer soil knowledge systems. Farmers were able to clearly characterise plots within their fields, that could match the soil variability that was measured. There was an understanding of soil physical characteristics especially soil texture and tilth, colour, crop production potential and soil erosion risks. Cost savings can result from well developed and widespread use of local soil indicators. Laboratory procedures are time consuming, costly and inaccessible to most smallholder farmers.

The involvement of farmers is key to sustainable land management and soil fertility replenishment approaches at all levels. To develop similar approaches, scientists and farmers should work together in on-farm research, to develop local soil knowledge so that farmers can effectively identify potential local soil resources and develop appropriate soil and crop management systems. Using local resources is advantageous in that local materials are easily available, and they are beneficial to soil quality. Some of the local soil organic compounds include manures and crop residues.

More research is needed through field experimentation and cropping trials to further develop soil–crop indicators as a basis for land quality management systems at agro-ecosystem levels. Through research, monitoring and collection of data on local soil indicators over longer periods of time, it may be possible to determine trends in land degradation.

Local soil knowledge is an important component of the agroecosystem, especially in low-input farming systems around the world. For this reason, indigenous knowledge of soil quality is an important entry point for scientists to understand and build on local soil–crop management practices. All soil knowledge, including those encapsulated in scientific learning were developed by people around the world, through their interaction with the environment and use of land resources. Consequently, the integration of scientific systems and indigenous knowledge should be viewed as a logical development in soil knowledge systems.

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