Assessment of farmers' perceptions of soil quality indicators within smallholder farms in the central highlands of Kenya

Mairura F.S.[1], Mugendi D.N.[1], Mwanje J.I.[1], Ramisch J.J.[2] and Mbugua P.K.[3]

[1]Department of Environmental Resource Conservation, Kenyatta University, P.O. Box 43844, Nairobi, Kenya; [2]Tropical Soil Biology and Fertility, P.O. Box 30677, Nairobi, Kenya; [3]Department of Botany, Kenyatta University, P.O. Box 43844, Nairobi; Author email for correspondence (fsmairura@yahoo.com)

Abstract

A study was conducted to determine farmers' perceptions of soil quality and soil management practices that influenced soil fertility within farmers' fields in Chuka and Gachoka divisions in central Kenya highlands. Soils were characterized by farmers after which they were geo-referenced and sampled at surface depth (0–20 cm) for subsequent physical and chemical analyses, to determine differences within farmers' soil quality categories. Special attention was given to agricultural weed species. Indicators for distinguishing productive and non-productive fields included crop yield, crop performance, soil colour and soil texture. A total of 18 weed species were used to distinguish between high and low soil categories. Significant differences among soil fertility categories implied that there were qualitative difference in the soils that were chacterised as different by farmers. Fertile soils had significantly higher pH, total organic carbon and exchangeable cations, with available-N being significantly different in Gachoka. Factor analysis on 15 soil properties identified 4 factors that explained 65% of the total variance in soil quality. Soil fertility and crop management practices that were investigated indicated that farmers understood and consequently utilized spatial heterogeneity and temporal variability in soil quality status within their farms as a resource to maintain or enhance agricultural productivity

Key words: Farmers, Indicator weed species, Local indicators, Scientists, Soil fertility, Factor analysis

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). Due to continuous intensive cropping, farmers have experienced declining crop yield over time (Mugendi et al., 1999), hence raising both scientific, and farmer environmental concerns over soil quality. Soil fertility declines at a rate that is largely governed by the type of land use systems introduced and their management (Zitong et al., 2003). Additionally many factors including soil management regimes within regions and farmers' fields contributes to soil variability, such that there are highly degraded soils within small landholdings in Africa.

Intensively managed landholdings in central Kenya typically contain three enterprise areas; namely, the 'outfields' mainly constitute cereal-legume intercrops intended for home consumption, 'infields' of market crops, and 'home sites' where livestock is confined and manures and composts are accumulated and kitchen gardens cultivated (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 market. The consistent nutrient 'mining' of 'outfields' results in nutrient deficient soils and crops that are characteristic of most small-scale farms (Murage et al., 2000). The spatial variability in soil fertility resulting from farm-level decisions about soil management is characterisable by indicators utilised by farmers and scientists. In Kenya, local soil indicators have not been fully evaluated in most smallhold farming systems, yet a scientific assessment of farmers' soil knowledge is needed to result in better soil

A. Bationo (eds.), Advances in Integrated Soil Fertility Management in Sub-Saharan Africa: Challenges and Opportunities, 1035–1046.

management by scientists and farmers. Until recently, scientists underestimated farmers' knowledge on soil fertility and management (Richards, 1985; Fairhead, 1992; Nandwa and Bekunda, 1998). Because of its' importance, a quantitative 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. However soil quality cannot be measured directly, but must be inferred from soil quality indicators and visual farmers' and scientsts' assesments. Many soil properties are correlated (Larson and Pierce, 1991), and must therefore be evaluated by statistical procedures that account for multivariate correlation among soil attributes. This study aims at evaluating soil quality indicators and variability by relating soil analysis and farmer soil quality perceptions within village enclaves that were sampled in Central Kenya Highlands, which are characterised by intensive soil management.The study was therfore undertaken, to identify indicators of soil quality status that were consistent with farmers' perceptions of soil quality. Assessment of soil quality is invaluable in determining the sustainability of Kenyas' agricultural practices. A comprehensive assessment of how farming communities recognize 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). As specific concepts, 'soil fertility' and 'soil quality' are used in congruity and in similar manner with Patzel et al. (2000). The objective of the study was to determine indicators of soil quality status that are consistent with farmers' perceptions of soil quality in Chuka and Gachoka divisions, in central Kenya. The fields that were studied were characterised by farmers into high and low fertility farm areas based on farmers experiences and indicators. The study aimed to find out if the farms identified as of high fertility had better soil properties compared to poor fields, based on means and multivariate evaluation of soil indicators.

Materials and methods

Site description

The study was conducted in two agricultural districts of central Kenya highlands, located approximately 150 km NE of Nairobi. Sixty farms were sampled in village enclaves of Kirege and Gachoka sub-locations in Chuka and Gachoka divisions respectively. Chuka division lies in the Upper Midland zone 2 and 3 (UM2–UM3) at an altitude of 1500 m, with an annual rainfall ranging from 1200–1400 mm (Jaetzold and Schmidt, 1983). Soil type is mainly Humic Nitisol with those in Gachoka being dominated by the Nito-rhodic Ferralsols (Jaetzold and Schmidt, 1983). The area is dominated by slope cultivation (up to 60%) 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

The study was conducted within the months of February and October in 2003. First, field instruments were pretested during the dry season in the month of February while the main study was conducted during the rainy season in the months of March to June. Farmers were asked to identify plots that they either regarded as productive (good quality) or non-productive (poor quality). Soil fertility indicators (weed species and descriptive indicators) with high and low productive soils were also recorded. Agricultural weeds that represented high and low fertility fields were recorded and sampled. The weeds specimen were collected, pressed, and identified at the Botany Department herbarium in Kenyatta University.

Soil sampling and analysis

Farmers were asked to characterise fields into high and low fertility farm sector units (Gachimbi et al., 2002), and these were later paired (Wardle, 1994). Soils were sampled in the long rain season. After geo-referencing (Tenywa et al., 1999), ten topsoil (0–20 cm) samples were collected from the top soil and composited. Subsamples (500g) were sealed and transported in cool boxes for laboratory analyses (Anderson and Ingram, 1993). Soils were analysed for texture, pH, calcium, magnesium, available nitrogen, soil organic carbon, total nitrogen, and phosphorous.

Soil texture was determined using the Bouyoucos Hydrometer method. Soil pH was determined by water extraction in a 1:2.5 ratio. Exchageable bases (Ca and Mg) were extracted in 1M KCl, followed by colorimetric and titrimetric determination respectively. For available P extraction, a 0.5M $NaHCO_3$ + 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 chromic (Cr^3) after soils were digested in acidified dichromate at 130ºC for 30 minutes. Total N and P were determined using the Kjeldhal Digestion method (Anderson and Ingram, 1993).

Data analysis

Social data was entered and analysed in SPSS version 11 (SPSS, 2002), while soil measurements were entered in Genstat. Soil parameters were compared by ANOVA in Genstat 5 Release 3 (Genstat, 1995), whereby the soil quality categories were the grouping variables (Wardle, 1994). Means for soil properties were separated using LSD stepwise separation. Factor analysis was used to study the relationship among soil variables, by statistically grouping 15 soil attributes into 4 factors (Brejda et al., 2000). 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 acceptable interpretation of the resulting factors.

Results and discussion

Indigenous knowledge and soil quality assessment

Descriptive soil indicators

The most important indicators included crop yield and crop performance that were utilised by more than 60% of the farmers in both divisions (Table 1). Other indicators included soil colour, soil texture, and agricultural weed species (Table 2). Usually, fields were characterised as either fertile or infertile, with indicators described dichotomously as either good or bad, or high or low. The most common indicators included crop yield, which was identified by 86% of the farmers in Chuka Division, as compared to 67% in Gachoka division. Other indicators in Chuka were crop performance (77%), soil colour (60%). The least common indicators were soil texture, fertiliser response, and soil moisture retention which were identified by less than 40% of the farmers. Table 1 shows the soil quality indicators utilized by farmers in both divisions.

Farmers used characteristics that they could see, feel, or smell in their fields, based on historic experiences in cultivating their fields and readily recognised that soil quality affected crop performance and yield. Crop characteristics are easily assessed by farmers, and their evaluation by scientists find them highly responsive to soil fertility. Despite descriptive soil indicators, farmers identified agricultural weed species that were found to be crucial visual criteria. 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). The dominance of soil texture and soil colour as a differentiating characteristic (Table 1) is common in farmer soil knowledge, which has been shown to tally formal soil classifications in ethnopedological studies (Talawar and Rhoades, 1997).

Table 1. 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	P-value
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

Agricultural weed species

On further probing, farmers identified agricultural indicator species. The high and low fertility indicator species are shown in Table 2. The most frequent high fertility indicator species (*Commelina benghalensis* L) was recorded on 77% of fields in Chuka division while in Gacohoka division it was Black jack (*Bidens pilosa* L.) found in 67% of the farms (Table 2). Additionally, the most frequent low fertility indicator weed species in Chuka division (*Melhania ovata* (Cav.) Spreng) was recorded on 67% of the fields, with a higher frequency for Gachoka division (93%) (Table 2).

Other indicators that were recorded on productive fields included the gallant soldier (*Galinsoga parviflora* L.) and *Amaranthus spp* which were recorded in 20% of the fields in Chuka division and 29% in Gachoka division (Table 2). Additionally, low fertility species included the goat weed (*Ageratum conyzoides* L.) which occurred on 37% and 10% of the fields in Chuka and Gachoka respectively (Table 2). The red top grass (*Rhynchelytrum repens* (Willd., C. E. Hubbard) was more frequent in Gachoka (70% as compared to Chuka (27%) cited by farmers as a low fertility indicator (Table 2). In both divisions farmers admitted that there was a high diversity of species on productive soils as compared to poor soils.

Species composition from Commelinaceae and compositae weed families were frequent as high fertility indicators in upto 50% of the fields in both divisions (Table 2). The Wandering Jew (*Commelina bengalensis* 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). Low soil fertility indicators included the red top grass (*Rhynchelytrum repens* (Willd.) C. E. Hubb). Several other studies that have been conducted in the region have found agricultural weeds similar to those found in this study. Globally, smallscale farmers have been reported to associate the nature and condition of vegetation, both native and planted with level of field soil fertility (Shaxson, 1997). However much of this knowledge is resident only in the minds of observant farmers and consequently needs to be further developed through balanced research designs. In Latin America, Suarez et al. (2001) found agricultural weeds to indicate the level of agricultural disturbance on soil productivity.

Table 2. Indicator weed species of high and low soil fertility stattus in Chuka and Gachoka divisions, Kenya

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

Table 3. Ranking and scoring of indicators by farmers in Chuka and Gachoka divisions

Indicator	Total score		Meanscore		Rank	
	Chuka	Gachoka	Chuka	Gachoka	Chuka	Gachoka
Crop yield	146	129	10	9	1	1
Crop performance	114	128	8	9	2	2
Soil colour	106	100	7	7	3	3
Soil tilth	96	97	6	6	4	4
Soilfauna	85	90	4	6	5	5
Soil texture	93	81	6	5	6	6
Fertiliser response	64	77	4	5	7	7
Soil moisture retention	70	75	5	8	8	8
Indicator species	64	64	4	4	9	9

[1] Scoring of indicators (Table 5) was based on a raking scale from 1–10, with 1 as the least important to 10 as the most important. Fifteen farmers in both divisions who were sampled for soils were involved in the ranking and scoring.

Farmer's ranking of indicators is shown in Table 3. Crop yield and crop performance were important indicators used by farmers, having been ranked number of 1 and 2 respectively in both divisions.The relative impotance of the indicators was almost similar, with a fairly high rank correlation (0.62). The agricultural weed species that were used are identified at species level (Table 3).

Farmers' perceptions of soil quality

As regards soils fertility status, farmers were requested to give information on their perceptions depending on whether they felt that their fields were of high or of low productivity. The results on soil quality perceptions are presented in Figure 1. In Chuka division, 35% of the farmers admitted that the status of their fields was low, which compared with 16% in Gachoka. Most farmers classified their fields as moderate (42% in Chuka and 64% in Gachoka). Additionally, only 14% and 9% of the farmers in Chuka admitted high and very high soil categories respectively, while there were none in Gachoka.

Farmers expressed their views that soil fertility was declining, stagnant or improving in diferent situations and soil erosion was regarded as a constraint to crop production. Most of the farmers in Chuka reported moderate (33%) to high levels (50%) of soil erosion, while in Gachoka low and moderate levels of soil erosion were realised. Erosion extent was determined by examining formation of rills and gulleys and by observing runoff during the wet seasons.

Contrasting responses over soil fertility changes were reported in both divisions. Most farmers reported

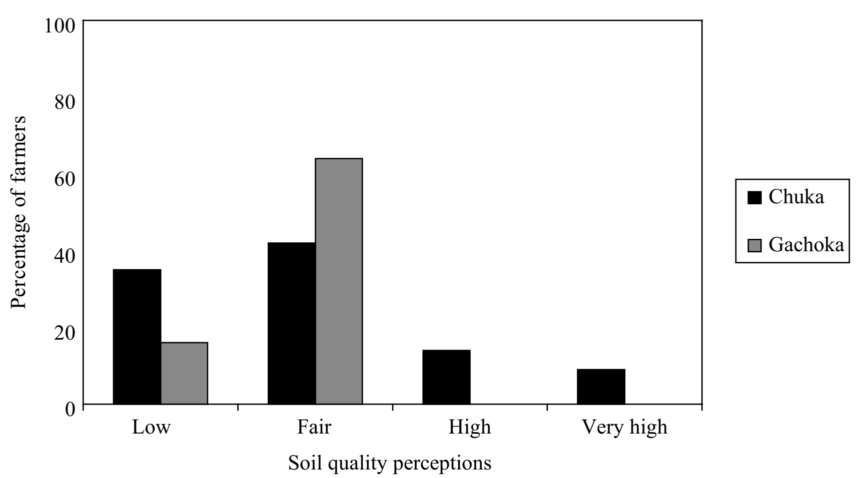

Figure 1. Perceptions of soil quality status by farmers at their fields in chuka and Gachoka divisions, Kenya.

that soil quality has been declining in both divisions, and realized that past soil management practices had influenced inherent soil fertility status. Shresta (2000) found conflicting results with soil fertility changes after intervewing different farmers who had cultivated continously for 30 years in Asia. This was also observed by Tabor et al. (1990) in Mbeere District, Kenya, and by Shaxson (1997). This is attributed to the fact that farmers evaluate soil fertility within their own fields (Tabor et al., 1990) and rarely undertake regional assesments.

Crop distribution and soil quality management

Different crops were cultivated in productive and non-productive fields, though some were also grown on both high and low fertility soils. The major crops included maize (*Zea mays* L.) and beans (*Phaseolus vulgaris* L.) in both divisions. Farmers in Gachoka mainly grew cereals, including finger millet and sorghum (*Sorghum bicolor* L.) that were intercropped with grain legumes. Tuber crops (cassava (*Manihot esculenta* L.), sweet potatoes (*Ipomea batatas* L.) and fodder grasses mainly occurred on poor soils in both divisions. Most smallholders in Chuka (83%) and Gachoka (80%) used fertilisers, averaging 37 and 21 kg $ha^{-1}yr^{-1}$respectively. The distribution of crops by soil fertility categories is shown in Table 4.

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, hence continuous intensive cropping systems prevalent in central Kenya. Farmers in the region therefore use fertilisers at less than 60kg N and P, that is nationally recommended (Cheruiyot et al., 2001) on valuable crops and preferred soils due to shortage in fertiliser inputs (Table 4). Additionally, organic resources and fertilisers are usually patchily applied within fields based on local perceptions of soil quality (J.J Ramisch, in press), and this indicated differences in soil mean properties in the high and low fertility plots that were analysed (Table 6). Routine agricultural practices, including rotation, planting, tillage and fertiliser application can create soil quality variation in the field (Gotway and Hergert, 1997). Recent research in Zimbabwe (Carter and Murwira, 1995) demonstrated how crop choice and field uses of organic and inorganic fertilizers are deliberately varied in accordance with small-scale variations in soil fertility conditions. In Zimbabwe as well as in central Kenya, farmers utilise spatial heterogeneity in soil fertility status within their fields as a means to maintain or enhance agricultural productivity.

Soil properties

Soil physical and chemical properties

In table 5 and 6, the means and SEDs of measured physical and chemical soil properties are presented, while the distribution for significant parameters is subesquently shown as box plots (Figures 2a–2f).

Clay averaged 33% and 35% for high and low fields in Chuka division, while it was approximately 31% in Gachoka on both soil categories. Additionally, sand averaged 38% in Chuka for both fields, while it was 67% and 64% for high and low fields in Gachoka. Silt was higher in the fertile fields in Chuka (29%), while poor fields had 27% silt content. In Gachoka soils, silt

Table 4. The distribution of crops on high fertile soils in Chuka and Gachoka divisions

Soil fertility categories	Crops	Divisions	
		Chuka (%)	Gachoka (%)
High fertility soils	Maize	93	50
	Beans	50	50
	Irish potatoes	50	–
	Bananas	70	–
	Sweet potatoes	88	100
	Cassavas	63	88
	Maize	13	–
Low fertility soils	Napier grass	67	77
	Sorghum	10	100
	Cowpeas	Not grown	65
	Millet	Not grown	100

Table 5. 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
	SED	3.7	3.7	5.0
Gachoka	High	30.3	67.1	2.7
	Low	32.9	64.0	3.1
	SED	5.5	3.2	5.0

Table 6. Soil chemical properties from high and low fertility sites in Chuka and Gachoka divisions

Soil Quality Category	TN	TP	C	N	P	Ca	Mg	PH
	%		$Mgkg^{-1}$			$cmol_c\ kg^{-1}$		
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

[1]For table 5 and 6, means followed by different letters in the same column are significantly different.

was negligible. There were no statistical differences in the soil physical means by land categories.

Mean clay and sand contents were almost similar on soil categories suggesting that the test sites were of similar pedogenic properties (Jaetzold and Schmidt, 1983), implying that the differences in chemical properties must have resulted from past soil management (Murage et al., 2000). The soils could thus be comparably evaluated (Karlen et al., 1994). Silt was slightly lower in poor sites in Chuka division, especially on sites that farmers had identified soil erosion as the main constaint to crop producition. Though the difference was not significant, this is congruent with the principle that silt is usually the first mineral component of the soil to be detached in water erosion processes (Brady, 1984).

Table 6 shows means of soil chemical properties in high and low soil categories.

The boxplots (Figures 2a–2f)indicate the distibution of different soil properties within the high and low fertility sites in Chuka and Gachoka divisions.

The productive soils showed higher soil C ($p < 0.05$) (Figure 2a), and exchangeable cations than infertile soils in both divisions, averaging Fertile fields in Chuka division showed a carbon level of 33.6 mg kg^{-1} as compared to 24 mg kg^{-1} for poor fields (Figure 2a). In Gachoka, low fertility carbon was also significant and averaged 12.5 mg kg^{-1} while the fertile plot mean was 15.2 mg kg^{-1}. Ca^{2+} ($p < 0.001$) (Figure 2b) was only significant in Gachoka division, while Mg^{2+} (Figure 2c) was higher ($p < 0.05$) in fertile sites in both divisions. On fertile soils, the mean calcium content was 8.2 mg kg^{-1}as compared to 7.5 mg kg^{-1} for poor soils in Chuka division while in Gachoka division, calcium was lower, averaging 5.8 mg kg^{-1} and 3.8 mg kg^{-1}on high and poor fields respectively. Soil reaction (pH) (Figure 2d) was higher in both divisions ($p < 0.001$) on soils that farmers identified as fertile. Soil pH averaged 5.6 and 5.1 in fertile and poor fields in Chuka division respectively. In Gachoka division, the fertile soils were slightly more basic than poor fields.

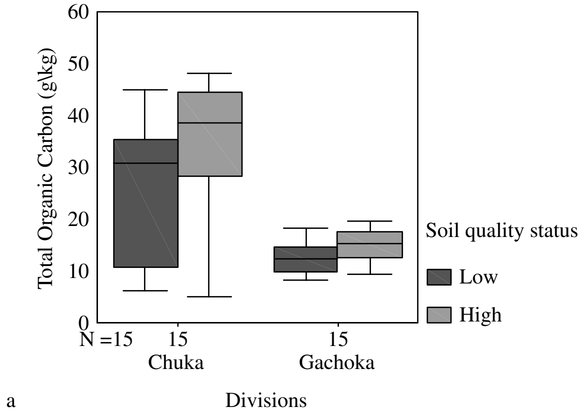

Figure 2a. Comparisons of total organic carbon.

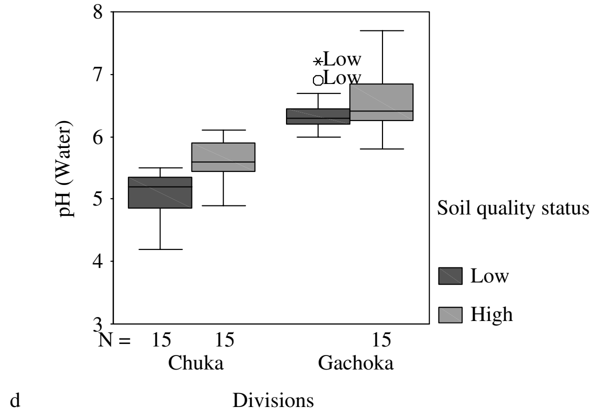

Figure 2d. Comparisons of soil reaction (pH).

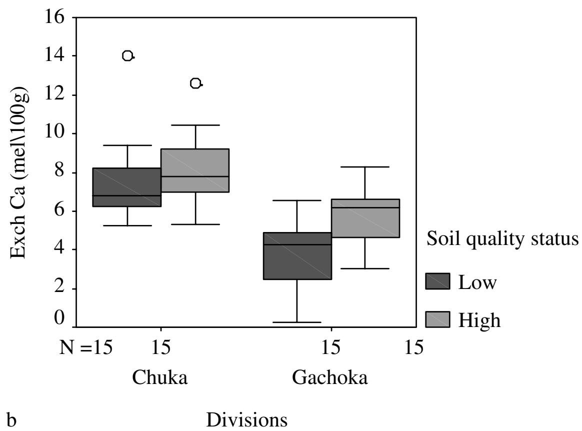

Figure 2b. Comparisons of exchangeable Ca.

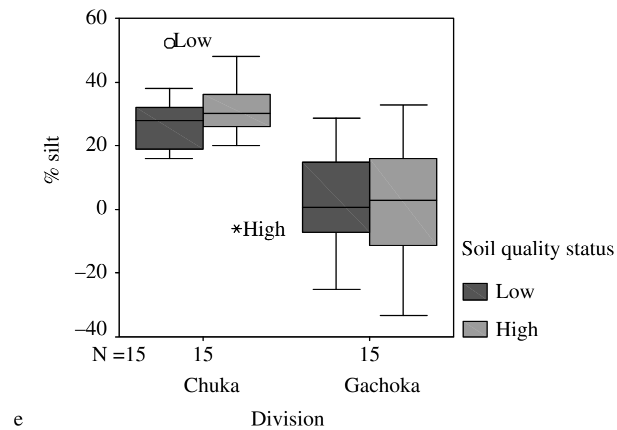

Figure 2e. Comparisons of extractable inorganic-N.

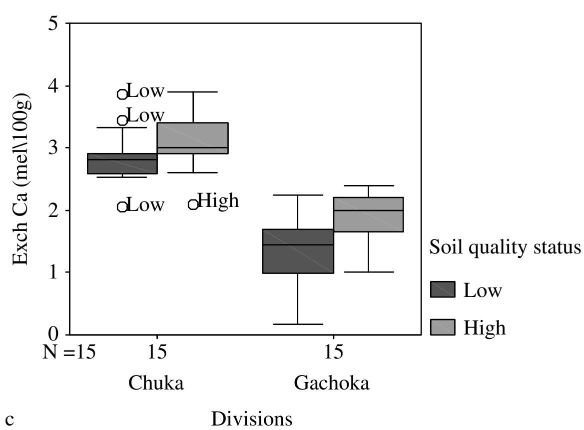

Figure 2c. Comparisons of exchangeable Mg.

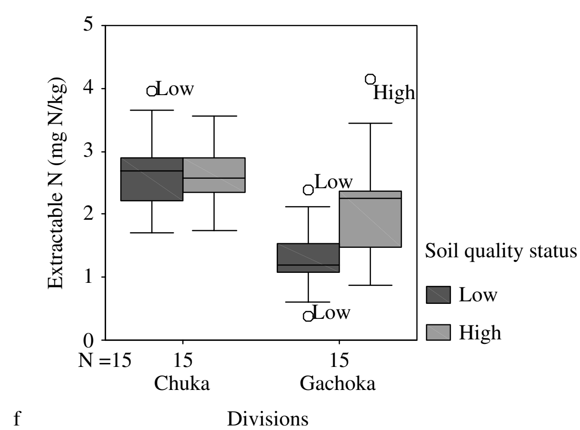

Figure 2f. Comparisons silt content.

Extactable inorganic-N (Figure 2e) was different ($p < 0.05$) in Gachoka soils while it was not different among sites in Chuka, averaging 2.8 and 2.7 mg kg^{-1}. The differences in Gachoka were 0.12 and 0.28 mg kg^{-1} ($p < 0.005$) for low and high fertility soil categories respectively (Figure 2e).

There were no differences in total P in both divisions suggesting it was not a sensitive indicator of soil quality. Total nitrogen in Chuka division averaged 0.16% (Table 6) in both farmer soil types. In Gachoka, total nitrogen ranged widely, averaging 0.16% and 0.002% for productive and non-productive soil categories respectively.

The 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 soils. Because exchangeable bases and pH are mainly influenced by soil organic matter, and the clay types and quantities were similar at poor and fertile soils (Table 5), 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) (Table 6). For magnesium, cropping intensity affects the amounts that are available in soil. Also, poorly managed fields that were more eroded may have led to faster losses of calcium and magnesium through leaching, hence a lower value.

Liebig and Doran (1999) compared farmers' soil knowledge along established assesment 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 querified using a written questionnaire. Their perceptions of soil quality indicators tended to match the scientific assessment closely for 'good' soils, but less so for 'problem' soils. Indicators that were incorrectly estimated at a frequency greater than 33% included available N and P, soil colour, degree of compaction, and infiltration rate. Despite this, farmers' perceptions were consistent for upto 75% of the time for the majority of indicators evaluated in the study. Arshad and Coen (1992) also found that many soil attributes can be estimated by calibrating quantitative observations against measured values and in tandem with Kundiri et al. (1997) and Halvorson et al. (1996), recommended that qualitative knowledge should be an integral part of soil quality information.

Available P indicated that soils in Chuka division had a higher capacity to supply P for crop growth, although this difference was not sigificant. However, twenty (20) of the 30 pairs within fields matchted consistently the soil categories that farmers had ascribed. The higher amount of readily available P in fertile soils may partly reflect higher fertilisation as associated with prefferential use of soil inputs on fertile soils and valued crops (Table 4) as compared to low quality soils (Schj onning et al., 2002). For Humic Nitisols that were cultivated in central Kenya, Murage et al. (2000) found significant differences for available P, though that was not the case inthis study.

The fertile soils reflected a higher capacity to hold nutrients than the non-productive soils in both divisions, due to higher exchangeable base cations, hence reflecting better crop yields and performance as identified by farmers. In fertile soils, farmers predominantly grew valued crops intended for market and these sites were also associated with animal sheds, where soil carbon accumulated. Conversely, planting of fodder grasses and lack of soil amendment characterised the poor fields. The consitent nutrient mining from poor fields eventualy leads to nutrient-deficient farm sector units. Murage et al. (2000) and Woomer et al. (1998) reported on-farm nutrient mining processes resulting in highly degraded fields and farm soil fertility gradients.

Soil factor analysis and variability

Table 7 shows the factor analyses for the measured soil properties, explaining the amount of variability accounted for by various soil factors. The 15 soil attributes initialy analysed were reduced by factor analysis to 4 main soil components by principle components analysis (PCA) with Varimax rotation. The first four factors explained 65% of the variance (Table 7), and had eigen values that were greater than 1 (Table 8).

The 4 reduced components (Table 8) were consequently retained for identification and interpretation (Brejda et al., 2000). Large 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 ± 0.3 were used to group and identify soil factors (Brejda et al., 2000). Table 8 shows the component matrix with corresponding loadings, eigen values, and communalities for extracted factors associated with soil parameters.

Table 7. Percentage of variance explained by soil factors in Chuka and Gachoka soils

Component	% of variance	% Cumulative variance
1	32.2	32.2
2	14.4	46.6
3	13.3	59.9
4	8.6	68.5
5	6.9	75.4
6	5.3	80.7
7	4.6	85.3
8	4.2	89.5
9	3.9	93.4
10	2.7	96.1
11	1.7	97.8
12	1.5	99.3
13	0.7	100
14	0.0	100
15	0.0	100
Total	100	

The first factor had a high positive loading on exchangeable magnesium (0.844), calcium (0.736), available nitrogen (0.743) and high a negative loading on soil pH (–0.677) (Table 8). As a result, the factor was identified as the 'exchangeable bases and soil acidity factor'. The second factor had fair loadings on total nitrogen, available nitrogen and organic carbon (0.379) (Table 8), which was identified as the 'organic matter factor', because it mainly comprised of soil organic resources. Component 3 recorded high positive loadings on extractable phosphorous (0.588) and available nitrogen (0.457). This factor was therefore identified as the 'fertility factor' (Table 8). The fourth factor mainly comprised of soil physical properties, with moderate positive loadings for macroaggregate stability (0.458), microaggregate stability (0.351), silt (0.305), and high negative loading for clay (–0.816) (Table 2). It was therefore identified as the 'soil physical factor'. The extracted factors also explained 57% of the variance in available phosphorous, carbon (58%), calcium (65%), pH (65%), clay (72%), total nitrogen (72%), silt (73%), magnesium (77%), sand (77%), total phosphorous (85%) and available nitrogen (89%), as indicated by their communalities (Table 8).

Based on the soil attributes that comprised them, all components in the four factor model (Table 8) 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 32% 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 14% of the soil variance in soil quality.

Table 8. Rotated factor loadings, eigen values and communalities for four factor model of physical and chemical properties in Chuka and Gachoka divisions

Soil attributes	Factor				Communalities
	1	2	3	4	
Exch Mg (me/100g)	.849	-6.484×10^{-2}	−.200	.113	0.777
Sand %	−.770	.219	.258	.248	0.769
Nitrate (mg N/kg)	.764	.258	.459	−.147	0.883
%silt	.754	−.108	−.232	.305	0.727
Available N(mg N/kg)	.743	.346	.457	-6.651×10^{-2}	0.886
Exch Ca (me/100g	.736	3.467×10^{-2}	−.304	.137	0.653
PH (Water)	−.677	.351	.261	1.862×10^{-3}	0.649
Total Organic Carbon	.557	−.344	.379	6.817×10^{-2}	0.577
Microaggregates	−.428	-3.730×10^{-2}	-8.664×10^{-2}	.351	0.315
% P	.129	.799	−.439	-7.116×10^{-2}	0.853
% N	.106	.734	−.391	−.124	0.719
Ammonium (mgN/kg)	-3.342×10^{-2}	.423	2.570×10^{-2}	.359	0.309
Olsen P (mg P/kg)	.193	.470	.558	6.814×10^{-3}	0.57
Clay %	-2.284×10^{-2}	−.198	−.134	−.816	0.723
Macroaggregates	.119	−.198	-6.450×10^{-2}	.458	0.267
Eigen values	4.592	2.15	1.571	1.365	

The ‘fertility management’ 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 13% of the soil variance, while the ‘physical factor explained 8.6% of the total variance. The communalities (Table 8) for chemical properties were generally higher than for soil physical attributes implying that they were more important in identifying soil factors and explaining the variation in soil quality (Brejda et al., 2000). This implies that exchangeable cations differed most spatially among soil nutrients. Exchangeable bases vary more than other soil elements (Arnon, 1992) due to soil management, including cropping and fertiliser uses (Kanwar, 1975).

The use of fertilisers on preferred fields (high fertility sites) and crops by the farmers (Table 4) partly explains the differences in calcium. Additionally, the losses due to leaching cations are usually very high, and mainly influenced by soil texture, and management regimes including cropping and fertiliser uses as reported by Kanwar (1975). In central Kenya, 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 (Table 4). This can explain differences in calcium due to changes induced in soil organic resources management regimes.

Conclusion

To assess a general soil quality status and to evaluate the potential for sustainable crop production, reliable measurements of soil quality should distinguish between contrasting sites, and at the same time, be sensitive to changes in management practices. Soil properties were analysed to substantiate indicators that were consistent with farmers’perceptions of soil fertility as was influenced by soil management. The results indicate that there were significant differences ($p < 0.05$) among soil fertility categories for key soil properties, suggesting that there was a qualitative difference in the soils that were characterised as different by farmers. This finding is important to recognise because it sets an entry point for closer examination of farmer soil knowledge systems. Farmers were able to clearly delianate plots within their fields, that could match soil variability that was measured. There was an undersanding of soil physical characteristics especially, soil texture and tilth, colour crop production potential and soil erosion risks. The significant differences between the high and low soil fertility niches identified by farmers for key soil properties, thus justified a qualitative difference in farmers soil categories. Using descriptive knowledge, farmers recognized that soil quality was not uniform over fields and that the differences among soils were readily observable. knowledge systems, which need to be viewed, not as opposing, but rather as complimentary to their own way of thinking.

Acknowledgements

We take this opportunity to appreciate the 60 farmers in Chuka and Gachoka divisions for availing their farms and to participate in the study. The TSBF (Tropical Soil Biology and Fertility) through the folk ecology project availed financial support to enable the study. We appreciate Mwangi Gichovi for support in the field, and Wilson Ngului for helping in laboratory analysis.

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