Comparing farmers' qualitative evaluation of soil fertility with quantitative soil fertility indicators in Kitui County, Kenya

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Title: Comparing farmers' qualitative evaluation of soil fertility with quantitative soil fertility indicators in Kitui County, Kenya

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Abstract

Soil fertility is vital for agricultural productivity, yet poor soils and erosion remain a management challenge in many parts of sub-Saharan Africa. One challenge is that soil scientists and farmers often evaluate soil fertility using different knowledge systems and the implications have not been clearly reconciled within the literature. In particular, whether farmers are observing similar aspects of structure and function as classified in soil science. If so, what can we learn about how soil fertility is evaluated and communicated in terms of developing a hybrid approach that improves communication of ideas between different stakeholders. This paper addresses this challenge by examining the similarities and differences between farmers' qualitative evaluation and soil science quantitative analysis for soil fertility classification, and how location of soils influence farmers' evaluation of soil fertility. Empirical fieldwork was carried out in two villages in Kitui County, Kenya with 60 farmers using semi-structured interviews and focus group discussion. Based on farmer perception, 116 soil samples of the best and worst soil fertility taken and analysed for physiochemical factors. Farmers had a consistent classification system and primarily relied on texture and colour as indicators for good soil fertility and texture alone for poor soils.

Soils with fine texture under the local semi-arid climate were associated with higher pH, TOC and WHC and fertile black and red soils were associated with pH, TOC, WHC and AP based on differences in bed rock. Poor soil fertility was associated with sandy soils and soils with no colour in their local name. Spatial location is an important consideration in farmers' evaluations, reflecting awareness of local diversity in soil and historical social or environmental factors. Local historical narratives reveal the importance in changes to humus, consistent with technical knowledge about the role of soil organic matter for soil fertility. The paper provides better understanding of farmers' soil classification, evaluation processes and perspectives that help to inform scientists working with alternative frameworks for assessment and, in doing so, supports the development of local tailor-made soil assessment systems.

Keywords: Ethnopedology, Soil fertility, Farmers' knowledge, Kenya

1. Introduction

Soil is the basis of life for both human food security and the building of the natural environment. Soil fertility information is essential to improve soil productivity and identify suitable land management. While soil scientists have developed chemical, physical and biological methods to measure soil fertility (Jones, 1982), evaluation is not limited to scientific measures, but is also qualitatively understood by farmers (Roland, Rubens and Azupogo, 2018). Criticism of the limited effectiveness of implementing top-down technology and scientific transfer of information through extension services has led to increasing attention on the value and integration of local knowledge held by farmers (Barrios and Trejo, 2003; Berazneva *et al.*, 2018; Guzman *et al.*, 2018; Richelle *et al.*, 2018). Fundamental presupposition of Eurocentric science are "*nature is knowable*" and Eurocentric scientists try to understand "*the structure and function of the whole in terms of the structure and function of its parts*"(Irzik 1998: 168). Indigenous knowledge is an empirical knowledge within local people accumulated with experiences, society-nature relationships, community practices and institutions, and by passing toward generations (Brokensha et al., 1980).
Farmers observe and evaluate their local soil experience for making everyday land management decisions (Rushemuka *et al.*, 2014; Bado and Bationo, 2018). Integrating local knowledge helps match extension workers efforts with local needs, and may achieve improved adoption of co-produced technology (Ingram *et al.*, 2018). Rocheleau (1988 cited in Walker et al. 1995) also point out that effective external interventions are best achieved 'once we know what they already know, and what else might be most useful to add to their store of knowledge and tools' (p236 in Walker et al. 1995). Farmers' evaluation of soil fertility is extensively reported as 'local' or 'farmers soil knowledge' in many ethnopedological studies (Barrera-Bassols and Zinck, 2003) and illustrates that farmers may understand aspects of function and scientific characteristics for their local soils but use different associations or framings to communicate and plan their land management.

Therefore, mutual understanding between farmers and scientists is not easy due to the ways that local knowledge systems contrast with scientific knowledge systems (Agrawal, 1995). Barrios et al. (2006) noted that while both systems share core concepts, such as the role of water for crop growth, each knowledge system has gaps and these are complemented by each other (Figure 1). They also argued that seeking a balance between scientific precision and local relevance expands shared knowledge to generate a new, hybrid knowledge system. Black (2000; p125-126) argued that "while many traditional problems may be solved with new methods, new problems, particularly environmental problems, may be best dealt with through a combination of new and traditional extension."

The starting point of soil fertility evaluation by farmers and soil scientists are same: the performance of crop growth (Vilenskii, 1957; Murage *et al.*, 2000). In addition, farmers also explain the characteristics of fertile or non-fertile soils, mainly by visual and morphological features, such as texture and colour which was used as universal criteria of soil fertility (Mairura et al. 2007 in Central Kenya; Kamidohzono et al.

2002 in West Sumatra). Even from the same starting point, the direction of interests is different. Soil scientists measure soil as a natural resource using quantitative analysis, while farmers evaluate soils as part of their daily experience in the field (Ingram, Fry and Mathieu, 2010). Farmers have more ‘know-how’ or ‘practical knowledge’ about soil, and scientists have more scientific knowledge or ‘know-why’ about soil (Ingram, 2008). These differences can be categorized into three main parts: perception of other environmental information; spatial scale; and timescale.

The first difference is the extent to which additional environmental information is used to evaluate soil fertility. Farmers’ evaluation of their soil is holistic (Barrera-Bassols and Zinck, 2003), where they see the soil resulting from a suite of interacting, complex environmental factors. For example, farmers often change their ranking of soil fertility based on seasonal rainfall (Osbahr and Allan, 2003). Moreover, from a geographical perspective, farmers perceive soil as the base for the environment, and thus local soil classifications incorporate land cover types (such as vegetation) (Duvall, 2008). By contrast, soil science reflects the reductionist approach used by natural science, which focuses on understanding “the structure and function of the whole in terms of the structure and function of its parts” (Irzik 1998: 168). Scientists often examine just one or two factors in isolation, for example in terms of their impact on crop performance. One scientific definition of soil fertility is “a soil that is fertile enough to provide adequate roots depth, nutrients, oxygen, water and a suitable temperature and no toxicities” (Wild 2003; 51). To explain the various factors, soil scientists focus on individual parameters and measure soil fertility predominantly by chemical and additional biological analysis or physical measurement in a laboratory and via direct measurement of environmental values (Landon 1984).

Second, farmers’ evaluation focuses on a smaller scale, related to farm, field and within-field plots, reflecting subtle understandings of soil diversity. Many studies have shown that local soil classification is more detailed than international soil classification (Barrera-Bassols and Zinck, 2003; Osbahr and Allan, 2003). It may be argued that farmers are able to evaluate soils in suitable ways for their farm management and soil scientists are able to generalize sample data to explain underlying patterns across landscapes and make maps. Of course, detailed local knowledge has the limitation of site specificity (Cook, Adams and Corner, 1998) and scientific soil classification or mapping can provide insights at regional, national and global scales. While the main reason for soil classification or mapping is use for planning of soil conservation and soil management improvement to lead to better plant growth, original baseline data for the classification of soils were generated by soil survey, topographic and geological mapping which relates to pedology and a focus on soil formation (Brady & Weil 1996). Originally, soil maps were designed to deliver information for managing landscapes and to create a common language of soils, with underlying general principles that explain complexity. Generalizations were necessary at landscape scale (Ashman and Puri, 2008) and thus the scale for farmer and science knowledge systems deviates.

The third difference is the timescale considered during evaluation. Farmers remember the history of their soils and how local knowledge has been shaped over a decades, including the influence of past management or specific events (that lead to improved soil or soil erosion for example) (Scott and Walter, 1993). By contrast, the timescale which soil scientists focus on differs; from the establishment of soil science, the pedological viewpoint is that soils form naturally over thousands of years (Yaalon and Berkowicz, 1997; Brady and Weil, 2016) but soil surveys for assessment focus on the immediate or current condition of the soil (often based on one-time sampling) (Landon, 1984).

The implications of these differences have not been clearly reconciled within the literature. In particular, whether farmers are observing similar aspects of structure and function as classified in soil science, and if so, what can we learn about how soil fertility is evaluated and communicated in terms of a hybrid approach. To address this challenge, this paper will: examine the similarities and differences between farmers' qualitative evaluation and soil science quantitative analysis for soil fertility classification; explore how the location of soils (e.g. villages and distance from home) influence farmers' evaluation of soil fertility. Location of soils includes the effect of social and environmental different and historical background of settlement. By examining these different approaches through a case study from Kenya, the paper will be able to highlight the potential value of improved awareness about local narratives of soil fertility, which reflect holistic knowledge systems and livelihood experience, and have implications for developing an integrated soil management approach.

2. Approach and Method

The role of the case study approach

The research approach adopted was to use an illustrative case study that enables capture of detailed local level understanding and to incorporate people (Yin, 2013), which may not be possible in a large scale soil study (Wilbanks and Kates, 1999). Kenya was selected because it is illustrative of a sub-Saharan developing country where agriculture dominates the national economy (Wambugu, Karugia and Oluoch-Kosura, 2011) with more than 70% of the population relying on small scale farming (Republic of Kenya, 2014).

Within Kenya, the research focused on Kitui County, located about 170 km east of Nairobi (Figure 2). The first rationale for selecting this county is the identification of contrasting soil types as recorded on the soil map for the region, resulting from the metamorphic bedrock and variation of slope (Mine & Geological Department Kenya colony North-West Quadrant, 1954; Sombroek, Braun and Pouw, 1980). The area has a semi-arid climate, with temperature between 14℃ to 34℃, and two rainy seasons: 'long' from March to May and 'short' from October to December approximately (County Government of Kitui, 2014). The exact period and amount of rain is erratic and unpredictable from year to year, with annual rainfall between 250mm and 1050mm (County Government of Kitui, 2013). The major ethno-cultural group is the

Kamba, and KiKamba is spoken by most people in Kitui County (KICABA Cultural Center, 2013). The Kamba have practiced livestock rearing, hunting and farming for centuries, introducing rhizome and pulse cultivation from the 17th Century (Ikeno 1989). The population living and farming on marginal lands have increased since the 20th Century when many Kamba moved from neighbouring Machakos to move from poor soils with high rates of degradation (Ikeno, 1989; Karanja *et al.*, 2017). Today, 87% of residents earn their livelihoods from agriculture using an average 2ha farm, with additional income from salary, casual local labouring and migrant work (County Government of Kitui, 2013). Both mixed and monoculture rainfed farming is practiced with maize, legumes, green grams, cowpea and pigeon pea as the main crops. Small numbers of livestock are owned and the manure is used to fertilise the fields, although the amount is limited. The use of chemical fertilizer is low due to the cost (Ralph *et al.*, 2006; County Government of Kitui, 2013). The second rationale for selection was the deep cultural rural farming knowledge and that a traditional land use system is practised, similar to other parts of Kenya. This land use system includes three types of enterprise areas: out-fields (away field), in-fields (home garden) and a home site (kitchen gardens) (Woomer *et al.*, 1998).

Within Kitui County, two villages were selected using purposive sampling (Tongco, 2007) to evaluate the effect of the difference of location for soil knowledge. Four criteria were used: (a) location in the same soil type based on the national soil map and in same Agro-Ecological Zone (AEZ); (b) a majority of villagers as smallscale farmers; (c) no active NGO activity or agricultural extension projects; (d) different distances from Kitui town centre and different frequency of communication with extension workers (one higher than the other). Soil types indicate soil general properties so they are assumed to affect farmers' perception of soils and fertility, and AEZ represents the climate condition of the area. Therefore, it was important to take data from the same high-level soil type and AEZ to reduce excessive variation of natural factors and focus on variation from social and management factors. The distance from town centre can affect the level of extension service, and therefore, access to scientific knowledge (Anderson, 2006). A national soil map, AEZ map (Sombroek, Braun and Pouw, 1980), and road map (WFP, 2007) of Kenya were processed on ArcGIS to identify the potential area and then shown on Google Earth. The national soil map (Sombroek, Braun and Pouw, 1980) identifies the study area as Um19; 'well drained, moderately deep to deep, dark reddish brown to dark yellowish brown, friable to firm, sandy clay to clay; in many place with top soils of loamy sand to sandy loam (ferralo-chromic/ orthic/ ferric ACRISOLS; with LUVISOLS and FERRALSOLS)' (p25). Acrisols and Luvisols are determined by the existence of Argic horizon (accumulation of clay) and classified by CEC (less than 24 $cmol_c\ kg^{-1}$ is for Acrisols and more than 24 $cmol_c\ kg^{-1}$ is for Luvisols) and base saturation (less than 50% for both) (IUSS Working Group WRB, 2015). Ferralsols are determined by a red colour and low activity clay minerals (IUSS Working Group WRB, 2015). The national soil map does not describe a finer level of soil differentiation. The bedrock is marked as area *Xg* on the Geological map for Kitui (Mine & Geological Department Kenya colony North-West Quadrant, 1954) and described as 'Microcline-oligoclase-biotite-hornblende migminte with biotite anplibolite schlieren granitic sheet and vien reticulation'.

Visits to villages to triangulate the soil data was conducted and, with support from Agricultural Extension, Village1 (Kavuti) and Village2 (Kitambasyee) were selected to represent locations with similar environmental conditions but different social conditions (Figure 3). GPS data showed elevation was similar (1180m in Village1 and 1000m in Village2) and field slope were similar with flat to moderately steep (0 to 25%) (Soil Survey Division Staff, 2017). Village1 was located near Kitui town (4.5 km) with historically frequent communication from Agricultural Extension officials - the village was located near the chief's office and where public meetings are held, a Ministry of Agriculture official lived in the village, and some farmers had relatives or friends who engaged with volunteer extension activities. Village2 was located 20km from the town, although due to limited transport it can take more than two hours to walk), and there was limited communication with Agricultural Extension officials.

Data collection: Farmer knowledge

Data was collected between January and October 2017. To understand the relationship between farmers' knowledge of soil fertility and soil physicochemical parameters, a mixed method approach was used (Robson, 2011). Information about farmers' evaluation of soil fertility was collected using individual interviews and a semi-structured guide to collect both qualitative and quantitative data (Robson, 2011).The questionnaire for interview was constructed with the questions to collect the data about the indicators of soil fertility, the location and scale of the best and the worst soil in farmers' fields. Although farmers are managers of different farms and recognize small difference even in the same field, this research focused on soils that farmers evaluated as the best or worst fertility location to avoid over-complexity. Approximately 50% of the total number of households in each village was randomly sampled and the person who decides management of their fields (usually the household head or wife) was selected as interviewees purposively inside each household. The total number of sampled farmers was 60 (30 in each village). Focus group discussions supplemented understanding of the historical narratives. Purposive sampling (Tongco, 2007) for participants was used as elder farmers (four farmers per a village, range of age is between 53 and 83 years old, who know historical change of soil and agriculture) were able to discuss the historical context. The questions for group discussion included previous soil condition and farmers' lifestyle, and social and environmental change affected on the change of soil fertility. A trained local translator was used for discussion between English and KiKamba, although some farmers spoke English. All data was recorded with permission.

Soil sampling and laboratory analysis

Soil samples were collected in August 2017 from the best and the worst fertile place in fields, as identified by each farmer. The sampling occurred just after harvest and the last short rains in fields that had not yet been prepared for next growing season. This was considered good timing for evaluating baseline soil nutrient status with minimal impact from additional inputs. Surface (10cm) soil samples were taken from

10 points within each field and bulked to make single composite samples of 500g. The total number of soil samples was 116, 59 from the best fertile locations and 57 from the worst fertile places. This was because four farmers had just one farm and one of them evaluated their field as not fertile only while another evaluated their fields as fertile only.

A sub-sample was sieved to 0.5mm for available phosphorus analysis. The remaining soils were sieved to 2mm for further analysis, stored to air dry at ambient temperature for use in other physical and chemical analysis. Nitrate-Nitrogen was measured within one week after sampling by extraction in 2.0M potassium chloride (KCl).

For soil physical measurements, colour of soils (wet and dry) was determined using a Munsell colour chart and texture using the ball and ribbon method (Thien, 1979). Water Holding Capacity (WHC) was measured by simplified method from soil laboratory in University of Reading. This process requires approximately 50 g of air-dry soil to be placed into a plastic container and then into a dish of water for 6 hours to allow saturation. Afterwards, containers were removed and covered to prevent evaporation, suspended on a retort stand to allow drainage and dried overnight. Approximately half of the wet soil from each container was removed and pre-weighed in an aluminium dish. Then a) the mass of the dish and b) the mass of the wet soil and dish were recorded and dishes put in an oven at 105 °C for 24 hours. Dishes were placed in a desiccator to cool and then weighed with mass recorded. The water holding capacity could be calculated as: WHC (%) = (mass of drained soil - mass of oven dried soil)/ mass of oven dried soil x 100.

For the chemical parameters, pH in H_2O (1:2.5) was measured using a glass electrode pH meter (Carter and Gregorich. 2008) and electronical conductivity ($EC_{1:1}$) was measured using a conductivity meter (Richards, 1954). The Total Organic Carbon (TOC) was determined by the Walkley-Black method (Walkley 1947), Kjedhal Method (Okalebo et al. 1993) was used for Total-Nitrogen (T-N), and Nitrate-Nitrogen (N-N) was extracted with 2.0 M KCL and measured by 0.01 *N* H2SO4 using an Auto-Titrator (Keeney and Nelson, 1982). Available Phosphorus (P) was measured by Mehlich 1 (Mehlich, 1953; Nelson, Mehlich and Winters, 1953), Exchangeable Potassium (K) and Sodium (Na) were extracted by ammonium acetate and measured using an atomic absorption spectrophotometer and Cation Exchange Capacity (CEC) was assessed with ammonium acetate after exchangeable cation extraction using the semi-micro distillation method (Lavkulich, 1981).

All data collection in Kenya was done under a research permit from National Commission for Science, Technology & Innovation (NACOSTI). All data from interview and focus group were received under University Ethical approval. Consent from partisans were taken before starting the data collection.

Data analysis

Qualitative interview data was treated first to coding (Coffey and Atkinson, 1996) to understand frequency of soil names, soil characteristics, location and scale of the best and worst soil in farmers' fields. Additionally, simple descriptive statistics were used. Narratives from the interviews and focus groups were organised to reveal insight to these identified patterns. Results from the soil physicochemical analysis were compared to farmers' evaluations to understand patterns and relationships and between the villages. Statistical analysis of quantitative data was performed using Minitab 17. Pearson chi-squared test was used to assess differences between 1) villages and farmer-selected location of the best and worst fertility soil, 2) farmers' soil fertility evaluation and local soil name, 3) villages and soil texture and 4) villages and locally determined soil colour classifications. A General Linear Model (GLM) was used to explore difference between the physicochemical data and farmers' evaluations of soil fertility. A multiple comparison approach was used to compare relationships between soil physiochemical data and soil texture/locally determined colour classifications. The results of TOC, TN, NN, AP, K, Na, CEC and EC took the Log of the data first and then fitted the GLM to the logged data to consider normality of residuals.

3. Results

Results from local soil knowledge analysis are presented first, including characteristics used by farmers to evaluate the best and the worst soil fertility, use of scale and location and farmers' terminology. Soil physicochemical parameters are then introduced and compared with farmers' evaluations of best and worst fertility to identify similarities and/or differences.

Farmer knowledge: Key soil properties used in farmers' evaluation of soil fertility

The characteristics of soils of the best and worst fertile places were described by farmer in response to an open question (Figure 4). Texture was the primary soil property used by farmers to evaluate both best and worst fertility. Colour was used to identify best fertility. There were other properties used by farmers, but these were less commonly used across the whole group. In total, 13 soil properties were identified as indicators for both best and worst soil fertility: texture, colour, workability, plant performance, water, stoniness, weed, feeling, fertilizer, location, root and sub-soil. Temperature was used only as an indicator for worst soil fertility.

When describing best soil fertility (n=59, Figure 4-a), farmers relied on fine soil texture (80%) and a black or red colour (55%) to describe the soil. Of the farmers, 27% recognized a difference in soil workability (e.g. the need for only moderate wetness to plough easily whereas with very wet conditions soils can be difficult), 22% referred to good plant performance and linked this to water availability (12%, "*Even in dry season, I felt moisture when I dig the place*" V2-6). Other facts mentioned included no stones (13%), a 'good feeling' for soils (8%), more 'fine' weeds (5%, "*It is easy to pull weeds out by hand*" V1-5), past use of fertilizer (5%, "*I added a lot of manure in the place in the past, so now here is fertile*" V1-4), location near house where there are often more inputs (5%), longer roots of plants (2%), and an observed different type of sub-soil (2%). When classifying the worst soil fertility (n=57, Figure4-b), texture was again the main factor (80%) but considered as course texture. A light soil colour (20%) was the second factor but reflect a smaller response in comparison to texture. Other indicators mentioned included difficult 'workability' of the soil (20%, "*The soil is too hard when it is dry so I need rain for plough.*" V1-16) less water availability (18%, "*The soil is dry faster due to drain faster*" V1-29) and poor crop performance (15%), more stones (13%), no fertilizer use (12%), many weeds (5%), far from the house (3%), a different type of sub-soils (3%, "*When dig the soil deeper, I found the red soil with shiny particles*" V2-6), hotness (3%, "*When I dig the soil in dry season for preparation, the sandy soil is too hot*" V2-15), small roots (2%) and a 'bad feeling' (2%).

Farmer knowledge: Role of farm scale and location

The scale of evaluation of soil fertility was very detailed within each farm. Farmers clearly understood differences in soil fertility. Out of the 60 interviewees, 88% were able to designate portions of their farm as the best or worst soil fertile place ("*The portion near tree is better than other because of supply of leaves.*" V1-26, "*My home field is located on slope so the bottom of slope is more fertile than up due to washed soil from up accumulate there.*" V2-13, "*There is a portion of natural black soil in the centre of my field and there is more fertile.*" V2-22) while 12% evaluated their whole farm as having the same soil fertility ("*The soil is same because my current field is quite small after dividing other for my children.*" V1-24).

Of the total sample, 46% selected the area around their house and inside the home-field as the primary location for best soil fertility. This kitchen garden or *Mũthĩo* (in Kikamba phonetic transcription, Whiteley & Muli 1962)is where livestock is often confined so manure and composts accumulate (Woomer *et al.*, 1998). The next best soil fertility area identified by the total sample was near to a river (20%). When comparing between the two villages, there are differences in response. Village1 reported that areas within their kitchen gardens were better (67%) than their away-fields (20%). In Village2, farmers evaluated their away-fields to have better soil fertility than kitchen gardens (24%) (the difference between villages is significant, Pearson chi-squared test P=0.006**). The influence of the river was important to soil fertility in Village2 (38%). There were also differences in the number of fields managed by farmers between the villages; Householders with more than two fields being managed was 33% in Village1 and 77% in Village2. This difference affected their selection of the best soil fertility locations on their farm overall with farmers in Village2 had more opportunity to use the good soils near the river.

Farmer knowledge: Local terminology for soil fertility evaluation

Farmers considered the fertility of soils through the healthiness of the crops grown. This connection was reflected in the articulation of soil fertility, with healthy (fertile) and non-healthy (unfertile) terminology used. Farmers perceived a connection between the healthiness of soils, plants and people (e.g. between good soils and production, food security and nutrition), and articulated this relationship using visual terms or outcomes (e.g. 'an overweight person would have fertile soil and more to eat'). In KiKamba, soil is called *Mũthanga* and the word for fertile is *Mũnou* so good fertility soil is described as *Mũthanga Mũnou*.

The word *Mũmosu* is used to describe a lack of fertility, and therefore poor soil fertility is *Mũthanga Mũmosu*. Interestingly, *Mũnou* and *Mũmosu* were also terms used for expressing human healthiness. A human being is called *Mũndũ* in KiKamba, with *Mũndũ Mũnou* used to refer to an overweight person, and often used to convey being healthy or having contentment. In contrast, *Mũndũ Mũmosu* is used to refer to an unhealthy thinness or something lacking in the human body. Technical or science-based crop performance indicators were not used by farmers as the first terminology to describe soil fertility (Figure 4) as farmers considered it necessary to reflect initially on the characteristics of *Mũthanga Mũnou* (or *Mũmosu*) and the collective healthiness of the soil and the crops.

Table 1 presents farmers' soil classification terms and how these relate to their designations of best and worst soil fertility on their farms. Farmers relied on 11 classifications, eight locally-defined terms and three defined in the English language. The eight locally-defined terms were divided into three groups: feature of soil; fertility classification; and formation type. There were five categories based on physical soil properties, including texture and colour, sandy soil (locally known as *Nthangathĩ*), black soil (*Mwiũ*), red soil (*Mũtune*), stony soil (*Kĩvuthĩ*) and black-clay soil found near rivers (*Ĩlimba*). Most answers were organised into these physical soil categories (91%) and KiKamba terminology was used for the majority of soil classification labels by farmers in Kitui. Although there were some synonyms and a few instances of mixes of category, it was still possible to consistently identify a dominant soil type with farmers. For example, in the category of *Mũtune* (red soil), there were two synonyms *Kĩtune* and *Ũtune* and a mix with *Ĩlimba* i.e. red soil with some black clay). Terminology for soil fertility can also be referred to as good (*Mũnou*) or bad (*Yalata*). There was just one category that reflected soil formation characteristics, which was a type of sedimentary soil called *Kĩvumbu* (other meaning of *Kĩvumbu* is clay soil found in termite mounds, personal communication with a local scientist). In addition to these local terms, three English terms were used to describe loam, clay and white soil.

There was a clear relationship between the terminology in farmers' soil classification and their evaluation of soil fertility (Table 1). Of the total, *Mũnou* (1 in 1), *Kĩvumbu* (1 in 1), *Ĩlimba* (12 in 12), *Mwiũ* (23 in 24), and *Mũtune* (13 in 19) were categories used to evaluate fertile soil. In contrast, course soil texture *Nthangathĩ* (29 in 34), *Kĩvuthĩ* (16 in 16) and *Yalata* (4 in 4) were used to evaluate poor fertility soils. The difference of local soil classification on farmers' fertility evaluation is significant (Pearson chi-squared test P=0.000***, with local soils including more than 10 soil samples used in the test), indicating that farmers were consistent in their use of local soil terminology and association of these terms with best and worst soils. In addition, there was a difference in occurrence of locally perceived soil types between the two study villages. *Mwiũ* and *Mũtune* (11 and 11 in 30) were dominant in Village1 and *Mwiũ* and *Ĩlimba* (12 and 11 in 29) were dominant in Village2 to describe good soil fertility. *Nthangathĩ* was dominant as the worst soil fertility in both villages, although *Kĩvuthĩ* was additionally recognized in Village2 as a worst soil fertility location. Notably, English terminology was only used in Village1.

Comparing local soil names with technical evaluations of texture, colour and physicochemical properties

Texture associated with each local soil classification was compared to scientific analysis of soil samples. The results of texture analysis made by a hand test were aggregated into three categories: clayey refers to clay dominated (>35% clay), including clay, sandy clay and clay loam; loamy describes moderately sandy, including sandy clay loam and sandy loam; and sandy, which is sand dominated (>75% sand), including loamy sand and sand. Clayey to loamy texture soil types were mainly classified from the best soil fertility locations, while course texture (sandy or stony) soils were classified from the worst soil fertility locations. *Kivuchi* and *Yalata* were classified as clayey to loamy texture using a hand test and those with significant stone content removed by sieving were classified as stony or course texture soils.

Soil samples were compared to a Munsell colour chart and named using the guide at https://logiteasy.com/free-tools/munsell-calculator.php. Soil colour was not significantly different across the soil classification by the chart. In total 11 soil colours were recognized but these were dominated by just three colour names (dark brown, dark yellowish brown and brown). *Ĩlimba* (6 in 12), *Mwiũ* (14 in 24), *Nthangathĩ* (16 in 34) and *Kĩvuthĩ* (7 in 16) were classified in dark brown, while *Mũtune* related to brown. The limited difference between soil colour name and local soil classification can be attributed to the naming system of the Munsell colour chart. The colour range to categorise dark brown, dark yellowish brown, brown and strong brown is wider than for other colours.

Table 1. Local soil classifications, with associated soil fertility and texture terminology (Source: Individual Interviews N=116 sites, 30 farmers)

Local soil name	**Meaning in English**	**No of samples**	**Fertility evaluation**		**Texture**		
			Best	***Worst***	***Clayey***	***Loamy***	***Sandy***
Mũnou	Good soil	1	1	0	1	0	0
Kĩvumbu	Sedimentary soil	1	1	0	1	0	0
Ĩlimba (Ĩlivĩ)	Black clay soil near river	12	12	0	6	6	0
Mwiũ (+Mũtune, +Nthangathĩ)	Black Soil	24	23	1	4	18	2
Mũtune (Kĩtune, Ũtune, +Ĩlimba, + Nthangathĩ)	Red Soil	19	13	6	13	5	1
Loam soil	-	2	2	0	1	1	0
Clay loam soil	-	1	1	0	1	0	0
No name	-	1	1	0	1	0	0
Nthangathĩ (+Mwiũ, +Mũtune)	Sandy Soil	34	5	29	4	12	18

Kĩvuthĩ (Kĩthathai, Ũthathai, +Mũtune, +Nthangathĩ)	Stony Soil	16	0	16	8	5	3
Yalata (Mwalata, Mwalata Mwiũ)	Bad Soil	4	0	4	2	2	0
White soil	-	1	0	1	0	0	1
Total		**116**	**59**	**57**	**42**	**49**	**25**

Table 2. Soil colour by local soil classification organised by the Munsell colour chart (wet conditions)

Local Soil Name	**Munsell Colour** *black*	*very dark brown*	*very dark grayish brown*	*dark grayish brown*	*Dark brown*	*dark yellowish brown*	*brown*	*strong brown*	*very pale brown*	*reddish brown*	*yellowish red*	**Total**
	10YR1.7/1	***7.5YR2/2, 2/3, 10YR2/3***	***10YR3/2***	***10YR4/2***	***7.5YR3/3, 3/4, 10YR3/3***	***10YR3/4, 4/4, 4/6***	***7.5YR4/3, 4/4, 5/4, 10YR 4/3, 5/3***	***7.5YR4/6, 5/6, 6/6***	***10YR7/4***	***5YR4/4***	***5YR5/6***	
Mũnou								1				1
Kĩvumbu							1					1
Ĩlimba (Ĩlivĩ)	1	3	2		6							12
Mwiũ (+Mũtune +Nthangathĩ)		1		1	14	2	5	1				24
Mũtune (Kĩtune, Ũtune, +Ĩlimba, + Nthangathĩ)					3	2	11	2		1		19
No name							1					1
Clay loam soil					1							1
Loam soil					2							2
Nthangathĩ (+Mwiũ +Mũtune)					16	13	5					34
Kĩvuthĩ (Kĩthathai, Ũthathai, +Mũtune +Nthangathĩ)					7	2	4	2			1	16
Yalata (Mwalata, Mwalata Mwiũ)					2	1	1					4
White soil									1			1

Total	**1**	**4**	**2**	**1**	**51**	**20**	**28**	**6**	**1**	**1**	**1**	**116**

Table 3. Physicochemical parameters of each local soil classification

Local soil name	**pH**	**TOC g kg^{-1}**	**TN g kg^{-1}**	**NN mg kg^{-1}**	**AP mg kg^{-1}**	**K cmol kg^{-1}**	**Na cmol kg^{-1}**	**CEC cmol kg^{-1}**	**EC ds/m**	**WHC %**
Best Fertility										
Mũnou	6.7	21.0	2.1	12.5	56	0.92	0.20	7.9	0.04	61.2
Kĩvumbu	7.4	10.1	3.4	19.3	114	0.42	0.23	14.1	0.05	55.7
Ĩlimba (Ĩlivĩ)	6.4	10.5	1.2	12.2	87	1.39	0.37	11.1	0.12	48.2
Mwiũ (+Mũtune, +Nthangathĩ)	6.7	10.6	1.1	11.6	109	1.16	0.43	10.3	0.09	42.0
Mũtune (Kĩtune, Ũtune, +Ĩlimba, +Nthangagi)	6.6	11.9	1.2	11.7	71	1.09	0.33	10.1	0.07	47.8
Loam soil	6.6	12.4	1.0	10.1	86	1.29	0.27	11.3	0.05	49.3
Clay loam soil	6.2	18.0	1.4	10.7	46	0.80	0.32	7.4	0.11	50.8
No name	6.5	19.5	2.5	17.7	21	0.76	0.19	10.8	0.05	57.5
Worst fertility										
Nthangathĩ (+Mwiũ +Mũtune)	6.1	10.0	1.0	11.3	49	0.92	0.32	9.4	0.07	35.5
Kĩvuthĩ (Kĩthathai, Ũthathai, +Mũtune, +Nthangathĩ)	6.1	9.2	1.2	11.9	65	1.39	0.38	10.7	0.06	42.8
Yalata (Mwalata, Mwalata Mwiũ)	6.2	10.8	1.1	11.3	84	1.49	0.30	9.5	0.10	44.6
White soil	6.1	6.6	0.5	9.5	18	0.64	0.26	10.6	0.12	45.4
Summary information										
Average (Best Fertility)	6.6	11.5	1.2	11.9	87.4	1.2	0.4	10.4	0.09	45.3
Average (Worst Fertility)	6.1	9.7	1.1	11.6	58.0	1.1	0.3	9.8	0.07	39.7
Average (All Samples)	6.4	10.6	1.2	11.7	73	1.1	0.4	10.1	0.08	42.5
Critical level	≧5.5	≧27	≧2	n.d	≧30	≧0.24	n.d	n.d	n.d	n.d

Results of the physicochemical analysis were also different between local soil types, which were classified into the best and worst soil fertility locations. When the physicochemical analysis was compared with critical levels for maize production (NAAIAP 2014), average values of pH, AP and K for all samples were higher and *Mũnou* and *Kĩvumbu* show higher TN. However, for other soils TOC and TN are deficient. This critical level indicates general deficiency of organic matter and sufficient mineral supply by bedrocks, which are locally categorized as metamorphic rocks (Mine & Geological Department Kenya Colony 1954). Therefore, it can be implied low organic matter in the soil.

The physicochemical analysis data was also statistically compared with the best and worst fertility soils. Using GLM analysis, soils from the best soil fertility locations were shown to have significantly higher average values than the worst soil fertility locations for pH (6.6 at the best/6.1 at the worst, P=0.000***), TOC (11. 5 and 9.7g kg^{-1}, P=0.003**), AP (87.4 and 58.0mg kg^{-1}, P=0.000***), K (1.2 and 1.1cmol kg^{-1}, P=0.032*) and WFC (45.3 and 39.6%, P=0.000***). However, while TN (1.2 and 1.1g kg^{-1}, P=0.088), NN (11.9 and 11.6mg kg^{-1}, P=0.396), Na (0.4 and 0.3cmol kg^{-1}, P=0.225), CEC (10.4 and 9.8cmol kg^{-1}, P=0.198) and EC (0.09 and 0.07ds/m, P=0.088) in the best fertility soils showed higher values than the worst fertility soils these results are not significantly different. The factors from location were additionally included in the GLM analysis. The difference of villages was found to be significant for pH, TOC, AP, K, Na, CEC, EC and WHC. The difference of field location (home- or away-field) particularly affected the value of WHC, with away-fields having higher WHC than home-fields.

Relationships between farmer' evaluation of soil fertility and soil physicochemical parameters

Further analysis was carried out to examine the relationship between farmers' local knowledge and technical knowledge obtained through the above physicochemical analysis with respect to the two key soil properties farmers use to assess fertility: texture and colour (Figure 4).

The difference in soil texture can be shown to be reflected in the values found in the physicochemical analysis (Table 4-a). First, frequency of appearance of the three texture classes used for best and worst fertility places is significantly different. For example, for the whole sample, the best fertility soil has a finer texture than the worst fertility soil (P=0.002**). The village location further affected the soil texture, with significantly more clayey soils in Village1 than Village2 (P=0.015*). This reflects the red clay soil (*Mũtune*) sampled in Village1. Additional exploration of the relationship between texture and physicochemical properties identified as significantly different between best and worst fertility soil and the location was performed (Table 4-b). The GLM models included soil fertility evaluation and location as factors and it was found that there is significant difference between all properties identified and the texture categories. Multiple comparisons on the 95% confidence interval show significant difference in pH, TOC and WFC among clayey, loamy and sandy texture. The respective values were higher for finer texture soils. The average values of AP, K and EC are higher for clayey, loamy and sandy respectively but the difference is not significant.

Table 4. Relationships between soil texture and (a) soil fertility evaluation or village location (Pearson chi-squared test) and (b) soil texture and the results of physicochemical analysis (multiple comparison) (N=116)

(a)		**Soil texture**			**P value**
		Clayey (N=42)	***Loamy (N=49)***	***Sandy (N=25)***	
Soil	**best**	24	30	5	0.002**

fertility evaluation	**worst**	18	19	20	
Village location	**1**	28	22	8	0.015*
	2	14	27	17	

(b)	**Soil texture**			**P value**
	Clayey	***Loamy***	***Sandy***	
pH	6.48^{a}	6.43^{a}	6.03^{b}	P<0.05
TOC g kg^{-1}	1.21^{a}	0.99^{b}	0.97^{b}	
AP mg kg^{-1}	76.0^{a}	76.1^{a}	64.20^{a}	
K cmol kg^{-1}	1.23^{a}	1.09^{a}	1.03^{a}	
EC ds/m	0.09^{a}	0.08^{a}	0.07^{a}	
WHC gH$_2$O gdry soil^{-1}	50.6^{a}	39.4^{b}	35.0^{c}	

**P <0.05, **P <0.01*

Although Table 2 does not show a clear difference for colour with local soil classifications, farmers rely on colour as an indicator for their evaluation of soil fertility. Therefore, further correlation between colours from farmers' classification and the physicochemical data was performed (Table 5). From the 116 soil samples, 105 which could be categorized into the five major local soil types were selected and ordered into three categories: Blackish (n=36) including *Ĩlimba* and *Mwiũ*, Reddish (n=19) including *Mũtune* and No colour mentioned (n=50) including *Nthangathĩ* and *Kĩvuthĩ*. There was a significant difference of appearance for each colour soils in soil fertility evaluation (P=0.000***) and between villages (P=0.017*) using a chi-squared test (Table 5-a). Blackish and Reddish soils were mainly classified as best soil fertility locations and no colour soils were found in the worst soil fertile areas. There was more Blackish soil and less Reddish soil in Village2 than Village1. This reflects the sample of *Mũtune* from Village1 and *Ĩlimba* from Village2. Multiple comparisons on the 95% confidence interval show a significant difference for pH, TOC, AP, EC and WHC among the Blackish, Reddish and No Colour soils. The average value of K is higher for Blackish, Reddish and No Colour respectively but the difference is not significant. The pH, TOC and WHC can be associated with changes in both colour and texture; AP and EC were associated with local colour only.

Table 5. Relationship between local soil colour and (a) soil fertility evaluation or village (Pearson chi-squared test) (b) and results of the physicochemical analysis (multiple comparison) (N=105)

(a)		**Colour of major local soil types**			**P value**
		Blackish (N=36)	***Reddish (N=19)***	***No Colour (N=50)***	
Soil	**best**	35	13	5	0.000

fertility evaluation	**worst**	1	6	45	
Village	**1**	12	14	23	0.017*
	2	24	5	27	

(b)	**Colour of major local soil types**			**P value**
	Blackish (N=36)	**Reddish (N=19)**	**No Colour (N=50)**	
pH	6.57[a]	6.62[a]	6.10[b]	P<0.05
TOC g kg^{-1}	1.05[ab]	1.19[a]	0.97[b]	
AP mg kg^{-1}	101[a]	71[ab]	54[b]	
K cmol kg-1	1.24[a]	1.09[a]	1.07[a]	
EC ds/m ^{1}	0.10[a]	0.07[ab]	0.07[b]	
WHC % gH_2O gdry soil^{-1}	47.8[a]	44.1[a]	37.8[b]	

**P <0.05, **P <0.01*

Soil evaluation and historical narratives

Farmers' narratives about their evaluation of soil fertility, classification and connection with social change were collected through focus group discussion with elder people and storytelling during individual interviews. In particular, farmers in both villages noted a change in local soil conditions compared with historical recollections were soils had become degraded, soil fertility had decreased and cultivation was more challenging: *"For the past generation of farmers, there was a lot of humus, fertile soil…if working this humus, it reached until the knee. The soil was covered by humus so we couldn't see the soil type"* (Village1); *"All the soils were black (Mwiũ) so you didn't need to recognize 'soil type' in the past. The head of the family always decides the best place by checking if the soil is loose, if it can be dug by hand and if there is a lot of humus… but nowadays after two or three seasons in cultivation, the soil fertility is a problem and the crops do not grow well. When you then dig the soil, it will make a noise [from the stones] …and this means is not a good field. In the past, the family could shift to other places as the land belonged to no one that time"* (Village2). However, the introduction of regulation in land ownership impacted traditional land use systems and ultimate the quality of the soil as "*after the surveyors came, they introduced new government rules and people were settled in the same place"* (Village1 and 2) limiting farmers' ability to practice extensive agriculture or even long-term fallow rotation.

With limited capacity for many farmers to practice intensive farming and maintain soil fertility, there are challenges for current soil fertility: *"The rain washes away the humus and top soils...after humus rich surface soil loss, other soils (Mũtune, Nthangathĩ, Kĩvuthĩ) now appear"* (Village1 and 2); *"The population in the village has increased and people here often cut the trees to make charcoal to sell, so the forest is reduced"* (Village1); *"the soil colour was originally black but now it is a bit pale and this means* *the soil has become old. My crop production has been reduced"* (Village2). Individual storytelling revealed that some farmers actively were attempting to practice low-cost improvement techniques through organic manures, soil and water conservation or mulching: *"when I moved to the place and built the new house, the soil was poor… but I collected leaves and humus from the forest and spread it over the field and it has made the soils more fertile"* (Village1).

4. Discussion

Having revealed the similarities between the characteristics used by farmers to evaluate best and worst soil fertility and the physicochemical analysis, this section reflects on why farmers understand the soil in the way they do. In particular, the reasons why farmers relied on texture and colour as their main indicators of soil fertility are explored. The factors that shape farmers' understanding include holistic information of farming experiences, historical social and environmental narratives, a detailed knowledge of the landscape and spatial scale.

Both local soil classification and evaluation of soil fertility in Kitui was dominated by soil texture and colour. The two is also main indicators in other local soil taxonomy (Barrera-Bassols and Zinck, 2003; Osbahr and Allan, 2003) and fertility evaluation (Murage *et al.*, 2000; Mairura *et al.*, 2007), and global soil classification(IUSS Working Group WRB, 2015). Kitui farmers used other fertility indicators including crop performance, roots growth, management effects, and workability which were observed and evaluated in their daily experience, through family and community knowledge, and from awareness of local field information (Ingram *et al.*, 2018). The appearance of macro-fauna or indicator plant species which mention in other studies (Murage *et al.*, 2000; Mairura *et al.*, 2007) were not answered from interviewees voluntarily in this study. It would be due to rare to see organisms on fields and less attention for weeds species than other indicators in the study area.

This simple approach to soil classification and evaluation may reflect the relatively short history of agriculture in this area. According to farmers' narratives of agricultural development in the region, soil knowledge and management has been shaped by social change. Traditionally farmers have evaluated the soil humus and texture to decide on the best locations for shifting cultivation since the 17th Century. These two indicators were also reported as common in indigenous soil classification in other areas (Barrera-Bassols and Zinck, 2003). However, these evaluations may not have been relied upon as much in the past because there was plentiful fertile land before 19th century. Increased settlement and the implementation of a land ownership system in the 1970's (Ikeno, 1989) restricted local farmers' traditional systems, with losses in the humus rich surface soil and soil erosion of some sub-soils. It is this reworked soil that is captured in the current local soil classification, but which may have been used for less than half a century. While nearby Machakos, another Kamba settlement, suffered degradation of its agricultural land up to the 1930s, a landownership system and introduction of terraces led to conservation improvements

(Karanja et al 2017, Tiffen et al. 1994). The story of agricultural extension in Kitui is however later than Machakos and there have been no large-scale land conservation project as within Machakos (Karanja et al 2017, Ikeno 1989, *personal communication with Extension Officers in Kitui*). Investment in terracing of fields has been ad hoc in Kitui and many have been damaged by high intensity rain. The growing population has placed pressure on forest resources, reduced farm sizes through traditional subdivision of land holdings for each generation, increased local food demand and required a more intensive farming approach (Ikeno, 1989). The narratives and soil knowledge reported by farmers in the study primarily reflects their experience after this period of social change.

Nevertheless, farmers construct a detailed local knowledge of their soils within their own farm, capturing small scale variation and a sense of connection with the history of their soil. Their local soil classifications focus on this small spatial scale, which is relevant to day-to-day farming decisions. This scalar dimension has been observed in other studies, in Niger (Osbahr and Allan, 2003) and in Rwanda (Rushemuka *et al.*, 2014). Location and connectedness with the landscape also shapes local soil evaluations. Land near to the family homestead or the river were seen as having the most fertile soil due to the availability of nutrients and water. The homestead benefits from organic waste, livestock and waste water (Woomer *et al.*, 1998) while the river supplies water and nutrients from deposited sediments. The type of sediments is decided by topography, with sand in the middle of the river while relatively flat sections allow clay with nutrients to accumulate (Brady and Weil, 2016). These areas are locally seen as demonstrating improved soils without labour input and classified as the best soil. Farmers are often more likely to focus further agricultural input in the most productive areas of their farm (Murage *et al.*, 2000).

There were differences in how farmers recognised soils between the two study villages. For example, while farmers in Village1 classified some soils on their farm in English, this was not the case in Village2. This reflected the availability of agricultural information in the school and access to an agricultural extension worker in Village1. There was difficulty in communication between extension workers and farmers in Village2 which was in a comparatively more remote area (Anderson, 2006). The positive effects of extension services in adding soil science-based knowledge to farmers is well known (Muyanga and Jayne, 2006). Extension staffs had informed farmers that *"Sandy loam soil was the best for cultivation of maize"* (*personal communication with Extension Officers in Kitui*), although a local term which meant "loam" did not exist in this area and farmers explained a loam texture as mixture of clay and sand. Another difference between the two villages was the selection of the location determined as the best or worst soil fertility. This can be attributed to a difference in availability of land. As illustrated by the number of farmers who have more than two fields (Village2 is higher), land is more difficult to acquire, buy or rent in Village1 because of a higher population density in the area since it is nearer to the town (The County Government of Kitui, 2014). Moreover, the elevation of Village1 is similar but bit higher than Village2 and the availability of black clay soil near river which made by alluviums is less than Village2. Farmers in Village1 have limited opportunity to use away-fields and consider differences in soil fertility on their owned fields as an effect resulting from better inputs and management than natural variation in soil type. As mentioned above, application of organic matter from house change the soil colour darker and increase black soils in local classification. While both intensification and natural diversity can lead to differences in texture and colour, the core concepts used by farmers for their evaluation of soil in both locations was the same. Given national interest in supporting intensification of these soils, understanding the underlying epistemological framings for management decisions by farmers are vital (Bozzola, Smale and Falco, 2016; Verkaart *et al.*, 2017).

Furthermore, there was consistency in aspects of the core concepts (figure 1) used to evaluate soil fertility by scientists using soil science methods and farmers local knowledge in Kitui. The results of the physicochemical analysis from locations identified by farmers as the best soil fertility areas were significantly better than those identified as the worst, and in particular this reflected a focus on organic matter content, pH, AP, K and WFC. This finding supports the argument by Murage et al. (2000) and Mairura et al. (2007) that Kenyan farmers' soil evaluation is highly consistent with soil science evaluations. Texture is the basis by which to understand soil structure and it is related to aeration, space for plant roots and moisture, which directly affect crop performance (Brady and Weil, 2016). Thus soil texture can indicate the potential level of nutrient and water holding capacity of a soil (Brady and Weil, 2016), which was identified to be significantly different in pH, TOC and WHC (Table 4) between the soils with different texture. coarse soils were determined by farmers to be problematic and often identified as the worst soil fertility location on their farm. This reflected their understanding of soil process, such as rapid drainage of water through the coarse soil particles, a problem in a region that experiences erratic rains and frequent drought spells because it leads to crop loss. Even if these are low-cost water conservation techniques, they can be labour intensive (Oguge and Oremo, 2018). The coarse particles are due to components from the metamorphic bedrock (Bishop, Woolley and Hamilton, 1999), especially silicate minerals such as microcline and oligoclase (Mine & Geological Department Kenya colony North-West Quadrant, 1954) which create sand. These sandy soils are considered problematic for farming locally and are called *Yalata* in KiKamba. Other studies have described coarse textured soils to be perceived as problematic by farmers (e.g. the *Tanah Tahinagan* soils in Indonesia) (Kamidohzono et al. 2002).

The colour of a soil is however often considered the most remarkable visual feature and can indicate a range of soil properties and processes. For example, there is a known correlation between a dark coloured soil and the amount of organic matter (Brady and Weil, 2016). In this study, significant differences were shown to be between local coloured soils and 'no colour' soils for pH, TOC, AP, EC and WHC. However, there was no significant difference between blackish and reddish soil. This reflects generally low organic matter content in the soils around Kitui, a problem which has been exacerbated by surface soil loss. Therefore, the relationship between darker soil and organic matter content is not clearly shown in this study. The colour of the soil can be explained by the clay types in this area. The source of the black colour clay described as *Mwiũ* or *Ĩlimba* was alluvial deposits, while the red clay of *Mũtune* came from the local iron-rich metamorphic rock (personal communication, Professor in Soil Formation, University of Nairobi). It can be concluded that farmers first evaluate their soils by texture, and second, they classify by the colour. Although soil colour in local classification is not clearly divided in Munsell colour chart but the space for further research of local colour epistemology is remaining as precise recognition of animal coat-colour among the Bodi in Ethiopia (Fukui, 1996).

Summarizing the achievements of this study as adapted in Figure 1 (Barrios *et al.*, 2006), Kitui farmers and soil science shares the use of soil texture and colour for soil fertility evaluation as core concepts. The information from farmers' observation and evaluation of field managements and history of social and environmental changes is lacking in soil science. On the other hand, the relationships between soil properties and soil process is less well understood by farmers, and the importance of organic matter is not mentioned by farmers at all, although it is dominant topic for water retention by soil scientists (Yageta *et al.*, no date; Brady and Weil, 2016). Water availability is a particularly challenging factor for agricultural production in Kitui and most farmers rely on rainfed supply, exposing them to the risk of drought (Ikeno, 1989). Instead of holistic (ref), Kitui farmers currently use qualitative indicators more readily than quantitative measures**.** Using soil colour and texture as an entry point and sharing of information about soil processes (or "know-why") about water and nutrient retention together with farmers empirical knowledge could help to provide a genuine two-way form of communication and social learning (Leeuwis and Aarts, 2011; Lie and Servaes, 2015). The creation of local tailor-made soil assessment systems using hybrid knowledge can integrate precise spatial information from farmers and the mechanisms of soil function from soil science, which would then provide the potential to support effective precision agriculture system (Osbahr and Allan, 2003) and increase sustainability and adaptability of soil management technology.

The results presented in this paper demonstrate that there is a epistemological question of the difference of soil colour and texture classification between farmers and soil science. Further work to explore the relationship around this in different locations, the differences among farmers, and to develop a deeper understanding of local understanding of the relationship between indicators and key soil processes in these different context would be useful. Although this study adopted a case study approach and results include site-specific data, the methods captured the main dimensions about farmers' perception of soil fertility and the similarity and dissonances with soil science knowledge – this illustrates how the impacts of location and historical narratives as social context shape soil knowledge beyond just a collection of local soil taxonomy (Niemeijer and Mazzucato, 2003).

5. Conclusion

Farmers in Kitui used a soil classification system based on local knowledge and evaluation processes of structure and function to assess soil fertility. The factors that shape farmers' understanding include holistic information of farming experiences with observation and evaluation, historical social and environmental narratives, a detailed knowledge of the landscape and spatial scale. Local historical narratives reveal the importance in changes to humus, consistent with technical knowledge about the role of soil organic matter for soil fertility. The main indicators used in evaluation of good soil fertility are texture and colour, while texture alone is used for poor soil fertility. This paper provides better understanding of farmer soil classification that help to inform scientists working with alternative frameworks, sharing the importance of soil colour and texture with farmers, providing the information of "know-why" and learn the importance of location from farmers. The two-way communication could create the hybrid knowledge which become a base for the development of integrated soil management approaches. Further research could investigate if systems of local soil colour classification and the role of local historical narratives is different in other contexts, as well as differences of understanding among farmers and the relationship between indicators and key soil processes. This paper has presented a straightforward approach for comparing qualitative and quantitative knowledge and the method could be used by extension workers in other locations.

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