

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

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

7

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19 **Abstract**

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

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

42

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

## 44 1. Introduction

45

46 Soil is the basis of life for both human food security and the building of the natural environment. Soil  
47 fertility information is essential to improve soil productivity and identify suitable land management. While  
48 soil scientists have developed chemical, physical and biological methods to measure soil fertility (Jones,  
49 1982), evaluation is not limited to scientific measures, but is also qualitatively understood by farmers  
50 (Roland, Rubens and Azupogo, 2018). Criticism of the limited effectiveness of implementing top-down  
51 technology and scientific transfer of information through extension services has led to increasing attention  
52 on the value and integration of local knowledge held by farmers (Barrios and Trejo, 2003; Berazneva *et al.*,  
53 2018; Guzman *et al.*, 2018; Richelle *et al.*, 2018). Fundamental presupposition of Eurocentric science are  
54 “*nature is knowable*” and Eurocentric scientists try to understand “*the structure and function of the whole*  
55 *in terms of the structure and function of its parts*”(Irzik 1998: 168). Indigenous knowledge is an empirical  
56 knowledge within local people accumulated with experiences, society-nature relationships, community  
57 practices and institutions, and by passing toward generations (Brokensha *et al.*, 1980).

58 Farmers observe and evaluate their local soil experience for making everyday land management decisions  
59 (Rushemuka *et al.*, 2014; Bado and Bationo, 2018). Integrating local knowledge helps match extension  
60 workers efforts with local needs, and may achieve improved adoption of co-produced technology (Ingram  
61 *et al.*, 2018). Rocheleau (1988 cited in Walker *et al.* 1995) also point out that effective external  
62 interventions are best achieved 'once we know what they already know, and what else might be most useful  
63 to add to their store of knowledge and tools' (p236 in Walker *et al.* 1995). Farmers' evaluation of soil  
64 fertility is extensively reported as 'local' or 'farmers soil knowledge' in many ethnopedological studies  
65 (Barrera-Bassols and Zinck, 2003) and illustrates that farmers may understand aspects of function and  
66 scientific characteristics for their local soils but use different associations or framings to communicate and  
67 plan their land management.

68

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

77

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

82 2002 in West Sumatra). Even from the same starting point, the direction of interests is different. Soil  
83 scientists measure soil as a natural resource using quantitative analysis, while farmers evaluate soils as part  
84 of their daily experience in the field (Ingram, Fry and Mathieu, 2010). Farmers have more ‘know-how’ or  
85 ‘practical knowledge’ about soil, and scientists have more scientific knowledge or ‘know-why’ about soil  
86 (Ingram, 2008). These differences can be categorized into three main parts: perception of other  
87 environmental information; spatial scale; and timescale.

88

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

103

104 Second, farmers’ evaluation focuses on a smaller scale, related to farm, field and within-field plots,  
105 reflecting subtle understandings of soil diversity. Many studies have shown that local soil classification is  
106 more detailed than international soil classification (Barrera-Bassols and Zinck, 2003; Osbaahr and Allan,  
107 2003). It may be argued that farmers are able to evaluate soils in suitable ways for their farm management  
108 and soil scientists are able to generalize sample data to explain underlying patterns across landscapes and  
109 make maps. Of course, detailed local knowledge has the limitation of site specificity (Cook, Adams and  
110 Corner, 1998) and scientific soil classification or mapping can provide insights at regional, national and  
111 global scales. While the main reason for soil classification or mapping is use for planning of soil  
112 conservation and soil management improvement to lead to better plant growth, original baseline data for  
113 the classification of soils were generated by soil survey, topographic and geological mapping which relates  
114 to pedology and a focus on soil formation (Brady & Weil 1996). Originally, soil maps were designed to  
115 deliver information for managing landscapes and to create a common language of soils, with underlying  
116 general principles that explain complexity. Generalizations were necessary at landscape scale (Ashman and  
117 Puri, 2008) and thus the scale for farmer and science knowledge systems deviates.

118

119 The third difference is the timescale considered during evaluation. Farmers remember the history of their

120 soils and how local knowledge has been shaped over a decades, including the influence of past  
121 management or specific events (that lead to improved soil or soil erosion for example) (Scott and Walter,  
122 1993). By contrast, the timescale which soil scientists focus on differs; from the establishment of soil  
123 science, the pedological viewpoint is that soils form naturally over thousands of years (Yaalon and  
124 Berkowicz, 1997; Brady and Weil, 2016) but soil surveys for assessment focus on the immediate or current  
125 condition of the soil (often based on one-time sampling) (Landon, 1984).

126

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

138

139

## 140 **2. Approach and Method**

141

### 142 *The role of the case study approach*

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

149

150 Within Kenya, the research focused on Kitui County, located about 170 km east of Nairobi (Figure 2). The  
151 first rationale for selecting this county is the identification of contrasting soil types as recorded on the soil  
152 map for the region, resulting from the metamorphic bedrock and variation of slope (Mine & Geological  
153 Department Kenya colony North-West Quadrant, 1954; Sombroek, Braun and Pouw, 1980). The area has a  
154 semi-arid climate, with temperature between 14°C to 34°C, and two rainy seasons: ‘long’ from March to  
155 May and ‘short’ from October to December approximately (County Government of Kitui, 2014). The exact  
156 period and amount of rain is erratic and unpredictable from year to year, with annual rainfall between  
157 250mm and 1050mm (County Government of Kitui, 2013). The major ethno-cultural group is the

158 Kamba, and KiKamba is spoken by most people in Kitui County (KICABA Cultural Center, 2013).  
159 The Kamba have practiced livestock rearing, hunting and farming for centuries, introducing rhizome  
160 and pulse cultivation from the 17<sup>th</sup> Century (Ikeno 1989). The population living and farming on  
161 marginal lands have increased since the 20<sup>th</sup> Century when many Kamba moved from neighbouring  
162 Machakos to move from poor soils with high rates of degradation (Ikeno, 1989; Karanja *et al.*, 2017).  
163 Today, 87% of residents earn their livelihoods from agriculture using an average 2ha farm, with  
164 additional income from salary, casual local labouring and migrant work (County Government of Kitui,  
165 2013). Both mixed and monoculture rainfed farming is practiced with maize, legumes, green grams,  
166 cowpea and pigeon pea as the main crops. Small numbers of livestock are owned and the manure is  
167 used to fertilise the fields, although the amount is limited. The use of chemical fertilizer is low due to  
168 the cost (Ralph *et al.*, 2006; County Government of Kitui, 2013). The second rationale for selection  
169 was the deep cultural rural farming knowledge and that a traditional land use system is practised,  
170 similar to other parts of Kenya. This land use system includes three types of enterprise areas:  
171 out-fields (away field), in-fields (home garden) and a home site (kitchen gardens) (Woomer *et al.*,  
172 1998).

173

174 Within Kitui County, two villages were selected using purposive sampling (Tongco, 2007) to evaluate the  
175 effect of the difference of location for soil knowledge. Four criteria were used: (a) location in the same soil  
176 type based on the national soil map and in same Agro-Ecological Zone (AEZ); (b) a majority of villagers  
177 as smallscale farmers; (c) no active NGO activity or agricultural extension projects; (d) different distances  
178 from Kitui town centre and different frequency of communication with extension workers (one higher than  
179 the other). Soil types indicate soil general properties so they are assumed to affect farmers' perception of  
180 soils and fertility, and AEZ represents the climate condition of the area. Therefore, it was important to take  
181 data from the same high-level soil type and AEZ to reduce excessive variation of natural factors and focus  
182 on variation from social and management factors. The distance from town centre can affect the level of  
183 extension service, and therefore, access to scientific knowledge (Anderson, 2006). A national soil map,  
184 AEZ map (Sombroek, Braun and Pouw, 1980), and road map (WFP, 2007) of Kenya were processed on  
185 ArcGIS to identify the potential area and then shown on Google Earth. The national soil map (Sombroek,  
186 Braun and Pouw, 1980) identifies the study area as Um19; 'well drained, moderately deep to deep, dark  
187 reddish brown to dark yellowish brown, friable to firm, sandy clay to clay; in many place with top soils of  
188 loamy sand to sandy loam (ferralsol-chromic/ orthic/ ferric Acrisols; with Luvisols and  
189 Ferralsols)' (p25). Acrisols and Luvisols are determined by the existence of Argic horizon  
190 (accumulation of clay) and classified by CEC (less than 24 cmol<sub>c</sub> kg<sup>-1</sup> is for Acrisols and more than 24  
191 cmol<sub>c</sub> kg<sup>-1</sup> is for Luvisols) and base saturation (less than 50% for both) (IUSS Working Group WRB, 2015).  
192 Ferralsols are determined by a red colour and low activity clay minerals (IUSS Working Group WRB,  
193 2015). The national soil map does not describe a finer level of soil differentiation. The bedrock is marked  
194 as area Xg on the Geological map for Kitui (Mine & Geological Department Kenya colony North-West  
195 Quadrant, 1954) and described as 'Microcline-oligoclase-biotite-hornblende migmatite with biotite



196 apllibolite schlieren granitic sheet and vien reticulation’.

197

198 Visits to villages to triangulate the soil data was conducted and, with support from Agricultural Extension,  
199 Village1 (Kavuti) and Village2 (Kitambasyee) were selected to represent locations with similar  
200 environmental conditions but different social conditions (Figure 3). GPS data showed elevation was similar  
201 (1180m in Village1 and 1000m in Village2) and field slope were similar with flat to moderately steep (0 to  
202 25%) (Soil Survey Division Staff, 2017). Village1 was located near Kitui town (4.5 km) with historically  
203 frequent communication from Agricultural Extension officials - the village was located near the chief’s  
204 office and where public meetings are held, a Ministry of Agriculture official lived in the village, and some  
205 farmers had relatives or friends who engaged with volunteer extension activities. Village2 was located  
206 20km from the town, although due to limited transport it can take more than two hours to walk), and there  
207 was limited communication with Agricultural Extension officials.

208

#### 209 *Data collection: Farmer knowledge*

210 Data was collected between January and October 2017. To understand the relationship between farmers’  
211 knowledge of soil fertility and soil physicochemical parameters, a mixed method approach was used  
212 (Robson, 2011). Information about farmers’ evaluation of soil fertility was collected using individual  
213 interviews and a semi-structured guide to collect both qualitative and quantitative data (Robson, 2011).The  
214 questionnaire for interview was constructed with the questions to collect the data about the indicators of  
215 soil fertility, the location and scale of the best and the worst soil in farmers’ fields. Although farmers are  
216 managers of different farms and recognize small difference even in the same field, this research focused on  
217 soils that farmers evaluated as the best or worst fertility location to avoid over-complexity. Approximately  
218 50% of the total number of households in each village was randomly sampled and the person who decides  
219 management of their fields (usually the household head or wife) was selected as interviewees purposively  
220 inside each household. The total number of sampled farmers was 60 (30 in each village). Focus group  
221 discussions supplemented understanding of the historical narratives. Purposive sampling (Tongco, 2007)  
222 for participants was used as elder farmers (four farmers per a village, range of age is between 53 and 83  
223 years old, who know historical change of soil and agriculture) were able to discuss the historical context.  
224 The questions for group discussion included previous soil condition and farmers' lifestyle, and social and  
225 environmental change affected on the change of soil fertility. A trained local translator was used for  
226 discussion between English and KiKamba, although some farmers spoke English. All data was recorded  
227 with permission.

228

#### 229 *Soil sampling and laboratory analysis*

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

234 10 points within each field and bulked to make single composite samples of 500g. The total number of soil  
235 samples was 116, 59 from the best fertile locations and 57 from the worst fertile places. This was because  
236 four farmers had just one farm and one of them evaluated their field as not fertile only while another  
237 evaluated their fields as fertile only.

238

239 A sub-sample was sieved to 0.5mm for available phosphorus analysis. The remaining soils were sieved to  
240 2mm for further analysis, stored to air dry at ambient temperature for use in other physical and chemical  
241 analysis. Nitrate-Nitrogen was measured within one week after sampling by extraction in 2.0M potassium  
242 chloride (KCl).

243

244 For soil physical measurements, colour of soils (wet and dry) was determined using a Munsell colour chart  
245 and texture using the ball and ribbon method (Thien, 1979). Water Holding Capacity (WHC) was measured  
246 by simplified method from soil laboratory in University of Reading. This process requires approximately  
247 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  
248 saturation. Afterwards, containers were removed and covered to prevent evaporation, suspended on a retort  
249 stand to allow drainage and dried overnight. Approximately half of the wet soil from each container was  
250 removed and pre-weighed in an aluminium dish. Then a) the mass of the dish and b) the mass of the wet  
251 soil and dish were recorded and dishes put in an oven at 105 °C for 24 hours. Dishes were placed in a  
252 desiccator to cool and then weighed with mass recorded. The water holding capacity could be calculated  
253 as:  $WHC (\%) = (\text{mass of drained soil} - \text{mass of oven dried soil}) / \text{mass of oven dried soil} \times 100$ .

254

255 For the chemical parameters, pH in H<sub>2</sub>O (1:2.5) was measured using a glass electrode pH meter (Carter  
256 and Gregorich, 2008) and electrical conductivity (EC<sub>1:1</sub>) was measured using a conductivity meter  
257 (Richards, 1954). The Total Organic Carbon (TOC) was determined by the Walkley-Black method  
258 (Walkley 1947), Kjeldhal Method (Okalebo et al. 1993) was used for Total-Nitrogen (T-N), and  
259 Nitrate-Nitrogen (N-N) was extracted with 2.0 M KCL and measured by 0.01 N H<sub>2</sub>SO<sub>4</sub> using an  
260 Auto-Titrator (Keeney and Nelson, 1982). Available Phosphorus (P) was measured by Mehlich 1 (Mehlich,  
261 1953; Nelson, Mehlich and Winters, 1953), Exchangeable Potassium (K) and Sodium (Na) were extracted  
262 by ammonium acetate and measured using an atomic absorption spectrophotometer and Cation Exchange  
263 Capacity (CEC) was assessed with ammonium acetate after exchangeable cation extraction using the  
264 semi-micro distillation method (Lavkulich, 1981).

265

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

269

## 270 *Data analysis*

271 Qualitative interview data was treated first to coding (Coffey and Atkinson, 1996) to understand frequency

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

284

### 285 **3. Results**

286

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

291

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

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

300

301 When describing best soil fertility (n=59, Figure 4-a), farmers relied on fine soil texture (80%) and a black  
302 or red colour (55%) to describe the soil. Of the farmers, 27% recognized a difference in soil workability  
303 (e.g. the need for only moderate wetness to plough easily whereas with very wet conditions soils can be  
304 difficult), 22% referred to good plant performance and linked this to water availability (12%, "*Even in dry*  
305 *season, I felt moisture when I dig the place*" V2-6). Other facts mentioned included no stones (13%), a  
306 'good feeling' for soils (8%), more 'fine' weeds (5%, "*It is easy to pull weeds out by hand*" V1-5), past use  
307 of fertilizer (5%, "*I added a lot of manure in the place in the past, so now here is fertile*" V1-4), location  
308 near house where there are often more inputs (5%), longer roots of plants (2%), and an observed different  
309 type of sub-soil (2%). When classifying the worst soil fertility (n=57, Figure4-b), texture was again the

310 main factor (80%) but considered as coarse texture. A light soil colour (20%) was the second factor but  
311 reflect a smaller response in comparison to texture. Other indicators mentioned included difficult  
312 ‘workability’ of the soil (20%, “*The soil is too hard when it is dry so I need rain for plough.*” V1-16) less  
313 water availability (18%, “*The soil is dry faster due to drain faster*” V1-29) and poor crop performance  
314 (15%), more stones (13%), no fertilizer use (12%), many weeds (5%), far from the house (3%), a different  
315 type of sub-soils (3%, “*When dig the soil deeper, I found the red soil with shiny particles*” V2-6), hotness  
316 (3%, “*When I dig the soil in dry season for preparation, the sandy soil is too hot*” V2-15), small roots (2%)  
317 and a ‘bad feeling’ (2%).

318

#### 319 *Farmer knowledge: Role of farm scale and location*

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

327

328 Of the total sample, 46% selected the area around their house and inside the home-field as the primary  
329 location for best soil fertility. This kitchen garden or *Mũthĩo* (in Kikamba phonetic transcription, Whiteley  
330 & Muli 1962) is where livestock is often confined so manure and composts accumulate (Woomer *et al.*,  
331 1998). The next best soil fertility area identified by the total sample was near to a river (20%). When  
332 comparing between the two villages, there are differences in response. Village1 reported that areas within  
333 their kitchen gardens were better (67%) than their away-fields (20%). In Village2, farmers evaluated their  
334 away-fields to have better soil fertility than kitchen gardens (24%) (the difference between villages is  
335 significant, Pearson chi-squared test  $P=0.006^{**}$ ). The influence of the river was important to soil fertility  
336 in Village2 (38%). There were also differences in the number of fields managed by farmers between the  
337 villages; Householders with more than two fields being managed was 33% in Village1 and 77% in Village2.  
338 This difference affected their selection of the best soil fertility locations on their farm overall with farmers  
339 in Village2 had more opportunity to use the good soils near the river.

340

#### 341 *Farmer knowledge: Local terminology for soil fertility evaluation*

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

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

356

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

372

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

385

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

395  
 396 Soil samples were compared to a Munsell colour chart and named using the guide at  
 397 <https://logiteasy.com/free-tools/munsell-calculator.php>. Soil colour was not significantly different across  
 398 the soil classification by the chart. In total 11 soil colours were recognized but these were dominated by  
 399 just three colour names (dark brown, dark yellowish brown and brown). *Īlimba* (6 in 12), *Mwiū* (14 in 24),  
 400 *Nthangathĩ* (16 in 34) and *Kĩvuthĩ* (7 in 16) were classified in dark brown, while *Mūtune* related to brown.  
 401 The limited difference between soil colour name and local soil classification can be attributed to the  
 402 naming system of the Munsell colour chart. The colour range to categorise dark brown, dark yellowish  
 403 brown, brown and strong brown is wider than for other colours.

404  
 405 Table 1. Local soil classifications, with associated soil fertility and texture terminology (Source: Individual  
 406 Interviews N=116 sites, 30 farmers)

Local soil name	Meaning in English	No of samples	Fertility evaluation		Texture		
			Best	Worst	Clayey	Loamy	Sandy
<i>Mūnou</i>	Good soil	1	1	0	1	0	0
<i>Kĩvumbu</i>	Sedimentary soil	1	1	0	1	0	0
<i>Īlimba (Īlivĩ)</i>	Black clay soil near river	12	12	0	6	6	0
<i>Mwiū (+Mūtune, +Nthangathĩ)</i>	Black Soil	24	23	1	4	18	2
<i>Mūtune (Kītune, Ũtune, +Īlimba, +Nthangathĩ)</i>	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
<i>Nthangathĩ (+Mwiū, +Mūtune)</i>	Sandy Soil	34	5	29	4	12	18

<i>Kivuthi</i>	<i>(Kithathai,</i>							
<i>Uthathai,</i>	<i>+Mūtune,</i>	Stony Soil	16	0	16	8	5	3
<i>+Nthangathi)</i>								
<i>Yalata (Mwalata, Mwalata</i>		Bad Soil	4	0	4	2	2	0
<i>Mwiū)</i>								
White soil		-	1	0	1	0	0	1
<b>Total</b>			<b>116</b>	<b>59</b>	<b>57</b>	<b>42</b>	<b>49</b>	<b>25</b>

407

408

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

410

Local Soil Name	Munsell Colour										Total	
	<i>black</i>	<i>very dark brown</i>	<i>very dark grayish brown</i>	<i>dark grayish brown</i>	<i>Dark brown</i>	<i>dark yellowish brown</i>	<i>brown</i>	<i>strong brown</i>	<i>very pale brown</i>	<i>reddish brown</i>		<i>yellowish red</i>
	<i>10YR1.7/1</i>	<i>7.5YR2/2, 2/3, 10YR2/3</i>	<i>10YR3/2</i>	<i>10YR4/2</i>	<i>7.5YR3/3, 3/4, 10YR3/3</i>	<i>10YR3/4, 4/4, 4/6</i>	<i>7.5YR4/3, 4/4, 5/4, 10YR 4/3, 5/3</i>	<i>7.5YR4/6, 5/6, 6/6</i>	<i>10YR7/4</i>	<i>5YR4/4</i>	<i>5YR5/6</i>	
<i>Mūnou</i>								1				1
<i>Kūvumbu</i>								1				1
<i>Īlimba (Īlivī)</i>	1	3	2		6							12
<i>Mwiū (+Mūtune +Nthangathī)</i>		1		1	14	2	5	1				24
<i>Mūtune (Kītune, Ūtune, +Īlimba, + Nthangathī)</i>					3	2	11	2		1		19
No name							1					1
Clay loam soil					1							1
Loam soil					2							2
<i>Nthangathī (+Mwiū +Mūtune)</i>					16	13	5					34
<i>Kīvuthī (Kīthathai, Ūthathai, +Mūtune +Nthangathī)</i>					7	2	4	2			1	16
<i>Yalata (Mwalata, Mwalata Mwiū)</i>					2	1	1					4
White soil									1			1



<b>Total</b>	<b>1</b>	<b>4</b>	<b>2</b>	<b>1</b>	<b>51</b>	<b>20</b>	<b>28</b>	<b>6</b>	<b>1</b>	<b>1</b>	<b>1</b>	<b>116</b>
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411

412 Table 3. Physicochemical parameters of each local soil classification

Local soil name	pH	TOC g kg <sup>-1</sup>	TN g kg <sup>-1</sup>	NN mg kg <sup>-1</sup>	AP mg kg <sup>-1</sup>	K cmol kg <sup>-1</sup>	Na cmol kg <sup>-1</sup>	CEC cmol kg <sup>-1</sup>	EC ds/m	WHC %
<b>Best Fertility</b>										
<i>Mūnou</i>	6.7	21.0	2.1	12.5	56	0.92	0.20	7.9	0.04	61.2
<i>Kīvumbu</i>	7.4	10.1	3.4	19.3	114	0.42	0.23	14.1	0.05	55.7
<i>Īlimba (Īlivī)</i>	6.4	10.5	1.2	12.2	87	1.39	0.37	11.1	0.12	48.2
<i>Mwiū (+Mūtune, +Nthangathī)</i>	6.7	10.6	1.1	11.6	109	1.16	0.43	10.3	0.09	42.0
<i>Mūtune (Kītune, Ūtune, +Īlimba, +Nthangagi)</i>	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
<b>Worst fertility</b>										
<i>Nthangathī (+Mwiū +Mūtune)</i>	6.1	10.0	1.0	11.3	49	0.92	0.32	9.4	0.07	35.5
<i>Kīvuthī (Kīthathai, Ūthathai, +Mūtune, +Nthangathī)</i>	6.1	9.2	1.2	11.9	65	1.39	0.38	10.7	0.06	42.8
<i>Yalata (Mwalata, Mwalata Mwiū)</i>	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
<b>Summary information</b>										
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

413

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

421

422 The physicochemical analysis data was also statistically compared with the best and worst fertility soils.  
 423 Using GLM analysis, soils from the best soil fertility locations were shown to have significantly higher  
 424 average values than the worst soil fertility locations for pH (6.6 at the best/6.1 at the worst, P=0.000\*\*\*),  
 425 TOC (11.5 and 9.7g kg<sup>-1</sup>, P=0.003\*\*), AP (87.4 and 58.0mg kg<sup>-1</sup>, P=0.000\*\*\*), K (1.2 and 1.1cmol kg<sup>-1</sup>,  
 426 P=0.032\*) and WFC (45.3 and 39.6%, P=0.000\*\*\*). However, while TN (1.2 and 1.1g kg<sup>-1</sup>, P=0.088), NN  
 427 (11.9 and 11.6mg kg<sup>-1</sup>, P=0.396), Na (0.4 and 0.3cmol kg<sup>-1</sup>, P=0.225), CEC (10.4 and 9.8cmol kg<sup>-1</sup>,  
 428 P=0.198) and EC (0.09 and 0.07ds/m, P=0.088) in the best fertility soils showed higher values than the  
 429 worst fertility soils these results are not significantly different. The factors from location were additionally  
 430 included in the GLM analysis. The difference of villages was found to be significant for pH, TOC, AP, K,  
 431 Na, CEC, EC and WHC. The difference of field location (home- or away-field) particularly affected the  
 432 value of WHC, with away-fields having higher WHC than home-fields.

433

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

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

438

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

452

453 Table 4. Relationships between soil texture and (a) soil fertility evaluation or village location (Pearson  
 454 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**

<i>fertility evaluation</i>	<b>worst</b>	18	19	20	
<i>Village location</i>	<b>1</b>	28	22	8	0.015*
	<b>2</b>	14	27	17	

455

(b)	Soil texture			P value
	<i>Clayey</i>	<i>Loamy</i>	<i>Sandy</i>	
<i>pH</i>	6.48 <sup>a</sup>	6.43 <sup>a</sup>	6.03 <sup>b</sup>	P<0.05
<i>TOC g kg<sup>-1</sup></i>	1.21 <sup>a</sup>	0.99 <sup>b</sup>	0.97 <sup>b</sup>	
<i>AP mg kg<sup>-1</sup></i>	76.0 <sup>a</sup>	76.1 <sup>a</sup>	64.20 <sup>a</sup>	
<i>K cmol kg<sup>-1</sup></i>	1.23 <sup>a</sup>	1.09 <sup>a</sup>	1.03 <sup>a</sup>	
<i>EC ds/m</i>	0.09 <sup>a</sup>	0.08 <sup>a</sup>	0.07 <sup>a</sup>	
<i>WHC gH<sub>2</sub>O gdry soil<sup>-1</sup></i>	50.6 <sup>a</sup>	39.4 <sup>b</sup>	35.0 <sup>c</sup>	

456 \*P <0.05, \*\*P <0.01

457

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

473

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

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

<i>fertility evaluation</i>	<b>worst</b>	1	6	45	
<i>Village</i>	<b>1</b>	12	14	23	0.017*
	<b>2</b>	24	5	27	

476

(b)	Colour of major local soil types			P value
	Blackish (N=36)	Reddish (N=19)	No Colour (N=50)	
<i>pH</i>	6.57 <sup>a</sup>	6.62 <sup>a</sup>	6.10 <sup>b</sup>	P<0.05
<i>TOC g kg<sup>-1</sup></i>	1.05 <sup>ab</sup>	1.19 <sup>a</sup>	0.97 <sup>b</sup>	
<i>AP mg kg<sup>-1</sup></i>	101 <sup>a</sup>	71 <sup>ab</sup>	54 <sup>b</sup>	
<i>K cmol kg<sup>-1</sup></i>	1.24 <sup>a</sup>	1.09 <sup>a</sup>	1.07 <sup>a</sup>	
<i>EC ds/m<sup>-1</sup></i>	0.10 <sup>a</sup>	0.07 <sup>ab</sup>	0.07 <sup>b</sup>	
<i>WHC % gH<sub>2</sub>O gdry soil<sup>-1</sup></i>	47.8 <sup>a</sup>	44.1 <sup>a</sup>	37.8 <sup>b</sup>	

477 \*P <0.05, \*\*P <0.01

478

479 *Soil evaluation and historical narratives*

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

495

496 With limited capacity for many farmers to practice intensive farming and maintain soil fertility, there are  
497 challenges for current soil fertility: *“The rain washes away the humus and top soils...after humus rich  
498 surface soil loss, other soils (Mūtune, Nhangathĩ, Kĩvuthĩ ) now appear”* (Village1 and 2); *“The  
499 population in the village has increased and people here often cut the trees to make charcoal to sell, so the  
500 forest is reduced”* (Village1); *“the soil colour was originally black but now it is a bit pale and this means*

501 *the soil has become old. My crop production has been reduced*” (Village2). Individual storytelling revealed  
502 that some farmers actively were attempting to practice low-cost improvement techniques through organic  
503 manures, soil and water conservation or mulching: *“when I moved to the place and built the new house,*  
504 *the soil was poor... but I collected leaves and humus from the forest and spread it over the field and it has*  
505 *made the soils more fertile*” (Village1).

506

#### 507 **4. Discussion**

508

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

515

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

526

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

539 (Karanja et al 2017, Tiffen et al. 1994). The story of agricultural extension in Kitui is however later than  
540 Machakos and there have been no large-scale land conservation project as within Machakos (Karanja et al  
541 2017, Ikeno 1989, *personal communication with Extension Officers in Kitui*). Investment in terracing of  
542 fields has been ad hoc in Kitui and many have been damaged by high intensity rain. The growing  
543 population has placed pressure on forest resources, reduced farm sizes through traditional subdivision of  
544 land holdings for each generation, increased local food demand and required a more intensive farming  
545 approach (Ikeno, 1989). The narratives and soil knowledge reported by farmers in the study primarily  
546 reflects their experience after this period of social change.

547  
548 Nevertheless, farmers construct a detailed local knowledge of their soils within their own farm, capturing  
549 small scale variation and a sense of connection with the history of their soil. Their local soil classifications  
550 focus on this small spatial scale, which is relevant to day-to-day farming decisions. This scalar dimension  
551 has been observed in other studies, in Niger (Osbahr and Allan, 2003) and in Rwanda (Rushemuka *et al.*,  
552 2014). Location and connectedness with the landscape also shapes local soil evaluations. Land near to the  
553 family homestead or the river were seen as having the most fertile soil due to the availability of nutrients  
554 and water. The homestead benefits from organic waste, livestock and waste water (Woomer *et al.*, 1998)  
555 while the river supplies water and nutrients from deposited sediments. The type of sediments is decided by  
556 topography, with sand in the middle of the river while relatively flat sections allow clay with nutrients to  
557 accumulate (Brady and Weil, 2016). These areas are locally seen as demonstrating improved soils without  
558 labour input and classified as the best soil. Farmers are often more likely to focus further agricultural input  
559 in the most productive areas of their farm (Murage *et al.*, 2000).

560  
561 There were differences in how farmers recognised soils between the two study villages. For example,  
562 while farmers in Village1 classified some soils on their farm in English, this was not the case in Village2.  
563 This reflected the availability of agricultural information in the school and access to an agricultural  
564 extension worker in Village1. There was difficulty in communication between extension workers and  
565 farmers in Village2 which was in a comparatively more remote area (Anderson, 2006). The positive effects  
566 of extension services in adding soil science-based knowledge to farmers is well known (Muyanga and  
567 Jayne, 2006). Extension staffs had informed farmers that “*Sandy loam soil was the best for cultivation of*  
568 *maize*” (*personal communication with Extension Officers in Kitui*), although a local term which meant  
569 “loam” did not exist in this area and farmers explained a loam texture as mixture of clay and sand. Another  
570 difference between the two villages was the selection of the location determined as the best or worst soil  
571 fertility. This can be attributed to a difference in availability of land. As illustrated by the number of  
572 farmers who have more than two fields (Village2 is higher), land is more difficult to acquire, buy or rent in  
573 Village1 because of a higher population density in the area since it is nearer to the town (The County  
574 Government of Kitui, 2014). Moreover, the elevation of Village1 is similar but bit higher than Village2 and  
575 the availability of black clay soil near river which made by alluviums is less than Village2. Farmers in  
576 Village1 have limited opportunity to use away-fields and consider differences in soil fertility on their

577 owned fields as an effect resulting from better inputs and management than natural variation in soil type.  
578 As mentioned above, application of organic matter from house change the soil colour darker and increase  
579 black soils in local classification. While both intensification and natural diversity can lead to differences in  
580 texture and colour, the core concepts used by farmers for their evaluation of soil in both locations was the  
581 same. Given national interest in supporting intensification of these soils, understanding the underlying  
582 epistemological framings for management decisions by farmers are vital (Bozzola, Smale and Falco, 2016;  
583 Verkaart *et al.*, 2017).

584  
585 Furthermore, there was consistency in aspects of the core concepts (figure 1) used to evaluate soil fertility  
586 by scientists using soil science methods and farmers local knowledge in Kitui. The results of the  
587 physicochemical analysis from locations identified by farmers as the best soil fertility areas were  
588 significantly better than those identified as the worst, and in particular this reflected a focus on organic  
589 matter content, pH, AP, K and WFC. This finding supports the argument by Murage *et al.* (2000) and  
590 Mairura *et al.* (2007) that Kenyan farmers' soil evaluation is highly consistent with soil science evaluations.  
591 Texture is the basis by which to understand soil structure and it is related to aeration, space for plant roots  
592 and moisture, which directly affect crop performance (Brady and Weil, 2016). Thus soil texture can  
593 indicate the potential level of nutrient and water holding capacity of a soil (Brady and Weil, 2016), which  
594 was identified to be significantly different in pH, TOC and WHC (Table 4) between the soils with different  
595 texture. coarse soils were determined by farmers to be problematic and often identified as the worst soil  
596 fertility location on their farm. This reflected their understanding of soil process, such as rapid drainage of  
597 water through the coarse soil particles, a problem in a region that experiences erratic rains and frequent  
598 drought spells because it leads to crop loss. Even if these are low-cost water conservation techniques, they  
599 can be labour intensive (Oguge and Oremo, 2018). The coarse particles are due to components from the  
600 metamorphic bedrock (Bishop, Woolley and Hamilton, 1999), especially silicate minerals such as  
601 microcline and oligoclase (Mine & Geological Department Kenya colony North-West Quadrant, 1954)  
602 which create sand. These sandy soils are considered problematic for farming locally and are called *Yalata*  
603 in KiKamba. Other studies have described coarse textured soils to be perceived as problematic by farmers  
604 (e.g. the *Tanah Tahinagan* soils in Indonesia) (Kamidohzono *et al.* 2002).

605  
606 The colour of a soil is however often considered the most remarkable visual feature and can indicate a  
607 range of soil properties and processes. For example, there is a known correlation between a dark coloured  
608 soil and the amount of organic matter (Brady and Weil, 2016). In this study, significant differences were  
609 shown to be between local coloured soils and 'no colour' soils for pH, TOC, AP, EC and WHC. However,  
610 there was no significant difference between blackish and reddish soil. This reflects generally low organic  
611 matter content in the soils around Kitui, a problem which has been exacerbated by surface soil loss.  
612 Therefore, the relationship between darker soil and organic matter content is not clearly shown in this  
613 study. The colour of the soil can be explained by the clay types in this area. The source of the black colour  
614 clay described as *Mwiũ* or *Īimba* was alluvial deposits, while the red clay of *Mũtune* came from the local



615 iron-rich metamorphic rock (personal communication, Professor in Soil Formation, University of Nairobi).  
616 It can be concluded that farmers first evaluate their soils by texture, and second, they classify by the colour.  
617 Although soil colour in local classification is not clearly divided in Munsell colour chart but the space for  
618 further research of local colour epistemology is remaining as precise recognition of animal coat-colour  
619 among the Bodi in Ethiopia (Fukui, 1996).

620

621 Summarizing the achievements of this study as adapted in Figure 1 (Barrios *et al.*, 2006), Kitui farmers  
622 and soil science shares the use of soil texture and colour for soil fertility evaluation as core concepts. The  
623 information from farmers' observation and evaluation of field managements and history of social and  
624 environmental changes is lacking in soil science. On the other hand, the relationships between soil  
625 properties and soil process is less well understood by farmers, and the importance of organic matter is not  
626 mentioned by farmers at all, although it is dominant topic for water retention by soil scientists (Yageta *et*  
627 *al.*, no date; Brady and Weil, 2016). Water availability is a particularly challenging factor for agricultural  
628 production in Kitui and most farmers rely on rainfed supply, exposing them to the risk of drought (Ikeno,  
629 1989). Instead of holistic (ref), Kitui farmers currently use qualitative indicators more readily than  
630 quantitative measures. Using soil colour and texture as an entry point and sharing of information about soil  
631 processes (or "know-why") about water and nutrient retention together with farmers empirical knowledge  
632 could help to provide a genuine two-way form of communication and social learning (Leeuwis and Aarts,  
633 2011; Lie and Servaes, 2015). The creation of local tailor-made soil assessment systems using hybrid  
634 knowledge can integrate precise spatial information from farmers and the mechanisms of soil function  
635 from soil science, which would then provide the potential to support effective precision agriculture system  
636 (Osbaahr and Allan, 2003) and increase sustainability and adaptability of soil management technology.

637

638

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

648

649

## 650 **5. Conclusion**

651

652 Farmers in Kitui used a soil classification system based on local knowledge and evaluation processes of

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

667

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669

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675

## 676 7. References

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