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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**

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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

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.

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 (Osbahr 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; Osbahr 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℃ to 34℃, 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 17th Century (Ikeno 1989). The population living and farming on

161 marginal lands have increased since the 20th 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 (ferralo-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 $cmol_c$ kg^{-1} is for Acrisols and more than 24

191 $cmol_c$ kg^{-1} 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 migminte with biotite

196   anplibolite 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 (%) = (mass of drained soil - mass of oven dried soil)/ mass of oven dried soil x 100.

254

255 For the chemical parameters, pH in H_2O (1:2.5) was measured using a glass electrode pH meter (Carter
256 and Gregorich. 2008) and electronical conductivity ($EC_{1:1}$) was measured using a conductivity meter
257 (Richards, 1954). The Total Organic Carbon (TOC) was determined by the Walkley-Black method
258 (Walkley 1947), Kjedhal 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 H2SO4 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 partisans 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 physiochemical 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

9

310 main factor (80%) but considered as course 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 *Mũmosu* is used to describe a lack of fertility, and therefore poor soil fertility is *Mũthanga*

349 *Mũmosu*. Interestingly, *Mũnou* and *Mũmosu* were also terms used for expressing human healthiness. A

350 human being is called *Mũndũ* in KiKamba, with *Mũndũ Mũnou* used to refer to an overweight person, and

351 often used to convey being healthy or having contentment. In contrast, *Mũndũ Mũmosu* 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 *Mũthanga Mũnou* (or

355 *Mũmosu*) 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*),

362 red soil (*Mũtune*), 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 *Mũtune* (red soil), there were two synonyms *Kĩtune* 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 (*Mũnou*) 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, *Mũnou* (1 in 1), *Kĩvumbu* (1 in 1), *Ĩlimba* (12 in 12), *Mwiũ* (23 in 24),

375 and *Mũtune* (13 in 19) were categories used to evaluate fertile soil. In contrast, course 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 *Mũtune* (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

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 course 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). *Ĩlimba* (6 in 12), *Mwiũ* (14 in 24),

400 *Nthangathĩ* (16 in 34) and *Kĩvuthĩ* (7 in 16) were classified in dark brown, while *Mũtune* 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*
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**

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
	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	
	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

14

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

411

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.

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^{-1}, P=0.003**), AP (87.4 and 58.0mg kg^{-1}, P=0.000***), K (1.2 and 1.1cmol kg^{-1},

426 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

427 (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},

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 (*Mũtune*) 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**

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

455

	Soil texture			P
(b)	*Clayey*	*Loamy*	*Sandy*	value
pH	6.48[a]	6.43[a]	6.03[b]	
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]	P<0.05
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]	

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 *Ĩlimba* and *Mwiũ*, Reddish (n=19) including *Mũtune* and No

463   colour mentioned (n=50) including *Nthangathĩ* 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 *Ĩlimba*

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)

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

18

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

476

(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]	
TOC g kg^-1	1.05[ab]	1.19[a]	0.97[b]	
AP mg kg^-1	101[a]	71[ab]	54[b]	P<0.05
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 % gH₂O gdry soil^-1	47.8[a]	44.1[a]	37.8[b]	

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 (Mũtune, Nthangathĩ, 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 17th 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 19th 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 *Ĩlimba* 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 (Osbahr 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 a 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 context 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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7. References

677

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