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Farmers' mental models of soil fertility in a semi-arid area of Kenya

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ABSTRACT

Effective knowledge exchange between farmers and other stakeholders, such as agricultural extensionists and soil scientists, is essential for increasing opportunities for sustainable soil fertility management. To achieve this, it is necessary to understand local farmers' conceptualisation of soil fertility. In a large body of works on local soil knowledge, the relationships of concepts constructing soil fertility knowledge and difference of knowledge among farmers have not been well documented. This study visualizes farmers' perceptions of soil fertility as aggregated mental models which represent cognition. Aggregated mental models of fertile and low fertility soils were created from data collected from 59 farmer interviews at two villages in Kitui County, Kenya. The share of respondents of each concept were shown to analyze the knowledge gaps among farmers and between villages. The mental models revealed that farmers recognize the important roles of soil texture, water availability and farm management in soil fertility. Their knowledge related to their lived experience of the actual productivity of soils, which resulted in a strongly different perspective of fertile and low fertility soil. The differences of perception between the villages were also recognized as the result of differences in land availability. Although the farmers who mentioned soil processes were very few, farmers had the potential to integrate further soil scientific knowledge. Consequently, using the mental model approach to visualize farmers' perceptions produced benefits by clarifying understanding of farmers' knowledge and identifying gaps where soil science and extension work could help to expand farmers' knowledge.

1. Introduction

Sustainable soil management underpins many of the UN Sustainable Development Goals (SDGs), particularly those supporting food production systems to deliver 'zero hunger' (UN, 2015; Bouma et al., 2019). Knowledge transfer as a one-way flow of information from scientist to farmer, via extension workers, is no longer seen as appropriate because this approach fails to recognize the value of Indigenous knowledge and the experience of farmers themselves (Ingram et al., 2010). If knowledge exchange is indeed essential for sustainable development (Ramisch, 2014; Krzywoszynska, 2019), learning and integrating farmers' knowledge fills the gap between science and farmers' empirical knowledge (Reed et al., 2014; Guzman et al., 2018; Stoate et al., 2019). Two-way communication between farmers and other stakeholders, such as scientists and extension officers, is needed to increase the suitability and sustainability of soil management programmes and land policies intended to combat land degradation (Berazneva et al., 2018; Wick et al., 2019).

Multi-disciplinary insights from the field of local knowledge of soils have revealed that farmers' knowledge systems are holistic, interconnected and reliant on hybrid forms of knowledge (e.g., Barrera-Bassols & Zinck, 2003; Osbahr and Allan, 2003; Pincus et al., 2018). In soil fertility studies, differences and similarities on indicators of soil evaluation between scientists and farmers are mainly reported (e.g., Ingram et al., 2010; Ramisch, 2014; Kyebogola et al., 2020). Soil properties including soil color, texture and moisture, and farmers' soil management practices are important for soil fertility recognition by farmers in Kenya (Mairura et al., 2007; Wawire et al., 2021) and other African countries (e.g., Buthelezi-Dube et al., 2020). The effect of social and topographic different on location also affects soil characteristics (Yageta et al., 2019; Wawire et al., 2021) However, the relationships among these concepts in farmers' knowledge is still unclear and

Abbreviations: WHC, water holding capacity; SSA, Sub-Saharan Africa.

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visualization of the entire structure of farmers' soil knowledge make benefit for deep understanding of farmers and knowledge exchange.

Mental models are cognitive representations of external reality (Jones et al., 2011) and they are used for understanding the plurality of stakeholders' perceptions of natural hazard and resource management (Jones et al., 2011; Prager and Curfs, 2016; Lalani et al., 2021). One type of mental model is the 'semantic web' (Novak and Growin, 1984). A semantic web diagram can show a set of concepts (nouns) as nodes within a network. Directional arrows labelled with relationship terms (mostly verbs) can be used to show relatedness between concept nodes (Wood et al., 2012). Semantic webs are more qualitative in nature than other methods used to create mental models, allowing rich visualization of an individual's cognitive understanding of a specific issue (Prager and Curfs, 2016). visualization through diagram-based representations of mental models provides a simple and understandable tool to identify potentials and overcome the limitations of stakeholders' knowledge (Morgan et al., 2002). Images also enhance dialogues among stakeholders, develop two-way (multi) communication and increase their engagement (Neset et al., 2019).

The mental model approach has not yet been applied to Kenyan farmers' soil knowledge. It can offer useful images regarding the linkage of soil properties, processes and soil management in farmers' knowledge, and enhance two-way (multi) communication. The use of semantic webs to show farmers' mental models directly adopts the approach used by Prager and Curfs (2016), which was used with farmers in Spain. In East Africa, many studies about farmers' soil knowledge have mainly observed as collective knowledge of certain community (Berazneva et al., 2018; Mairura et al., 2007). Occelli et al. (2021) have revealed the influence of the difference of soil knowledge toward crop production. Aggregated mental models are created to understand the general structure of farmers' knowledge in certain communities (Halbrendt et al., 2014 in Nepal; Vanermen et al., 2020 in Belguim) but the differences in understanding of soil fertility among individual farmers in same community is not well documented. Even in a same ethnic group, location of living affect farmers' communication channel and knowledge construction (Anderson, 2006; Spurk et al., 2020). This study aims to respond to the need for improved understanding of farmers' soil knowledge through the creation of mental models of soil fertility, exploring their perception on soil fertility and the role of management to improve soil fertility. This study chooses to create aggregated mental models of sampled farmers in same community and show the share of respondents of each concept. It can reveal the overall structure of soil fertility knowledge in the community and knowledge gap among the farmers. The objectives of this paper are to: (1) develop farmers' mental models of fertile and low fertility soils within a mixed cropping and livestock farming system in a semi-arid climate in Kenya; (2) reveal the relationship of concepts constructing fertile and low fertility soils, soil management and location of soils; and (3) examine any differences in knowledge about soil fertility among farmers and between villages. The implications of new insights will help explore whether understanding farmers' mental models of soil fertility can help to enhance communication between farmers and other stakeholders, such as soil scientists and policy maker.

2. Material and methods

2.2. Location of data collection

Kitui County, Kenya, was selected for this study because it has low soil fertility and limited precipitation, which associated with low agricultural productivity (County Government of Kitui, 2018). The area has a semi-arid climate with a mean annual temperature between 14℃ and 34℃. There are two rainy seasons, with the main precipitation period between October and December, followed by March and May (County Government of Kitui, 2014). The total annual rainfall range is between 250 mm and 1050 mm and the timing within the season can be highly erratic (County Government of Kitui, 2018, 2013). The majority of households (87%) rely on agriculture to earn a livelihood (County Government of Kitui, 2018). Small-scale farmers grow maize, legumes, green gram, cowpeas and pigeon peas on small farms (averaging 4.4 ha), and depend on the rains for cultivation (Oremo, 2013; County Government of Kitui, 2018). While most farmers keep livestock, the amount of organic manure used on their fields is generally insufficient for soil fertility maintenance (County Government of Kitui, 2013) and the high cost of chemical fertilizer is prohibitive (Ralph et al., 2006; County Government of Kitui, 2013;).

Two villages (Kavuti: Village 1 and Kitambasyee: Village 2) were selected by purposive sampling (Tongco, 2007) using four criteria: (a) location with the same soil type (Um19) in the national soil map, and with the same Agro-Ecological Zone (AEZ) (marginal cotton zone (vs/*s* + *s*/vs)) (Sombroek et al., 1980); (b) different distances from Kitui town center and different frequency of communication with extension workers (that in the closest being higher than in the more remote location); (c) no active NGO activity or agricultural extension project. These criteria allow the study to evaluate the effect of locational difference on soil knowledge. The legend "Um19" in the national soil map included ferralo-chromic/orthic/ferric Acrisols with Luvisoils and Ferralsols, according to the World Reference Base (WRB) (Sombroek et al., 1980). These soil types were characterised by clay and low nutrients (IUSS Working Group WRB, 2015). Village 1 was located near Kitui town (4.5 km) with historically frequent interaction with extension officers - the village was located near the chief's office where public meetings were held, a Ministry of Agriculture official lived in the village, and some farmers had relatives or friends who engaged with volunteer extension activities. Village 2 was located 20 km from the town which could take approximately one hour due to limited transport by public buses and motorbikes, and there was limited communication with agricultural extension officials.

2.3. Collecting data on farmers' soil knowledge

To create aggregated farmers' mental models of soil fertility, qualitative data from farmers about key concepts of soil fertility including soil properties, processes, management and location was collected through a participatory method, casual diagram (Galpin et al., 2000). Farmers were individually interviewed for revealing the different perceptions by each farmer and villages. Then the collected data was sorted and counted the share of respondents of each concept to show the knowledge gaps between village and among farmers. Finally, the aggregated mental models were drawn.

Data collection was conducted from May to October 2016 by the first author. In the two sampled villages, 29 households in Village 1 and 30 households in Village 2 (approximately 50% of the total number of households in each village), total 59 households were randomly sampled. Within each household, the person with responsibility for the family farm (usually the household head or the spouse) was invited to be the interviewee. Causal diagram (Galpin et al., 2000), a participatory method to link the related concepts by arrows with farmers, was used for data collection. This tool is useful for in-depth analysis of issues together with farmers. It is mainly used for identification of causes of problems (Galpin et al., 2000) but it was used for identification of causes and indicators of high and low fertile soils in this study. Following Reynolds and Gutman (1988) and Okello et al. (2019), farmers were asked to select the area on their farm with 'the best fertility' in their opinion and asked "Which crop varieties were cultivated in that area?". Then they were asked "Why they planted those crops in that location", and encouraged to give their reasons until they had no more answers (e.g., *"Bean is planted in the fertile soil because it grows well here. the reason of grow well was because I added manure and plant residue in clayey soil. Residues bring the fertility but I don't know the reason"* V1_10). The same questions were repeated for fields on their farm which farmers considered to have 'low fertility'. This interview method helps the interviewees to dig into their subconscious mind and increase their answers more than when they ask only one question (Okello et al., 2019). Of the 59 farmers (8 males and 51 females), four farmers had just one field, of whom one evaluated their field as only low fertility, while another evaluated all their fields as fertile. Therefore, 58 (29 in Village 1 and 29 in Village 2) answers for the most fertile places and 56 (27 in Village 1 and 29 in Village 2) for the less fertile places were collected. The data on farmers' soil fertility evaluation were compared with physical and chemical assessments of the soil in a companion study (Yageta et al., 2019). All communications were in English and the local language, KiKamba; a trained local translator acted as an interpreter. All data collection in Kenya received a research permit from the National Commission for Science, Technology & Innovation (NACASTI). Consent from participants was given before data collection.

Collected data for fertile soil was sorted and categorized (e.g., 'heavy soil', and 'sticky soil' were categorized as 'clayey soil') manually on Excel 2016 and the dominant answer was selected as the representative concepts. A word-association software (http://khc.sourceforge.net/en/" http://khc.sourceforge.net/en/) called KH coder was used for counting the share of respondents in total and per each village and checking the connection between the concepts. This software has been used in the analysis of public opinion, mainly in Japan (Maeda, 2015; Tsukada and Morita, 2018). The links between the representative concept were connected with manually selected relationship terms, according to the farmers' qualitative data. The same process was repeated for the creation of the sematic web of low fertility soil.

The prioritized focus of this research is to reveal the fundamental understanding of soil fertility by farmers in the selected locations. Although there were some minor differences in farmers' understanding between villages and the rates of some answers were low, data was explored as an aggregate between the two villages, given the overall similarity in knowledge. Gender differences were not explored in the answers and it would be because the farm in this area was managed under the corporation of family members.

3. Results

The interview data revealed that Kitui farmers focused on different aspects of fertile and low fertility soils. Hence, two aggregated mental models of farmers' understanding of soil fertility were produced to show the differences, one for 'fertile' and the other for 'low fertility' (Fig. 1 and 2). The percentages in this result section indicate the share of respondents who mentioned the concept at least once. To emphasize the contrast, these answers were categorized as the main (≧10%) and minor (<10%) concepts in the aggregated mental models which mean majority view for main and minor as minority views. Majority view is what consensus sits and minority pulls out some of the differences among farmers. The different focus for each of the two villages was also revealed (Table 1). All farmers' reasons for planting these specific cash crops in fertile soil were because of 'good harvests (Fig. 1). The farmers' mental model of low fertility soil also started from the good productivity of specific crops that were tolerant of drought and a limited supply of nutrients, (Fig. 2). Through the data sorting process, three thematic areas emerged to characterize farmers' perceptions with both fertile and low fertility soils: soil property, soil management and specific location. Farmers emphasised the soil properties when describing poor quality soils. The comparison of two mental models categorized by each thematic area is described below.

3.1. Perception of soil fertility in farmers' mental models

The aggregated model of fertile soil shows a large variation in farmer knowledge, with only >20% farmers agreeing on three key properties: water holding capacity (WHC) (24%), good water availability (28%) and clayey texture (24%). Water was associated with soil's physical properties, particularly texture. Of the sampled farmers, 24% specifically mentioned WHC (or 'soil moisture') as a sign of fertility. Clay textured soils (24%) were associated with good water holding capacity (*"Heavy (clayey) soil hold more water but I don't know the reason"* V2_18). Farmers described soil suitability for a certain crop as a determining factor for identifying whether soil would be suitable for cash crops (16%), including hybrid high-yield maize varieties, vegetables and fruits. The 'wetness of soil' was related to water availability for crops (28%). Cash-crop production on clayey soils were seemed better than on coarse soils (9%). Some farmers said a mix of particle size (5%) was preferable for crops which needed moderate moisture (*"Mixture of clay and loam is good for Duma43 (a hybrid maize variety)"* V1_7). A few farmers described the loose texture (7%), which some considered an important characteristic for the growth of crop roots (3%). Concentrations of high fertility soils were recognised by a black soil color (5%).

The key soil properties associated with low fertility soil were much greater agreement among farmers about. Discussion of soil properties focused on specific types that were characterised as sandy (59%) or stony (21%). Coarse textured soil was known to decrease WHC (13%) and therefore induce lower water availability (45%). However, poor-quality soils were still perceived to be useful for particular crops (32%), those that were tolerant of drought or limited nutrients including cowpeas, pigeon peas, green gram, cassava and some maize varieties (18%). Course textured soil was favourably considered by farmers as allowing good rooting systems (14%) which was also mentioned in the mental model of fertile soil. Only a few farmers noted the relationship between coarse soil texture, lack of compaction (4%) ("*Sweet potato is planted in this soil (low fertility) because stony soil makes no compaction and grow well"* V1_3) and the rate of water penetration (4%) (*"Stony soil dry up faster. Water through pore around stones because soil cannot absorb water"* V2_2). One farmer mentioned waterlogging problems on sandy soil after excessive rainfall (*"This sandy soil water logged in heavy rain"* V1_15). Farmers felt that soils with a low soil water content contributed to their 'hot' soil temperatures in dry conditions (7%).

3.2. How to improve soils

For fertile soil, 45% perceived the application of soil amendments, such as fertilizer, animal manure, plant residue and domestic organic waste, as a way to improve soil fertility, while 14% felt this was important because of the added nutrients essential for plant growth ("*Manure and fertilizer add nutrients"* V1_15). Only each one farmer (2%) was able to describe the process of decomposition of organic matter in the soil (*"I added swiped leaves from home to this (fertile) place. Leaves rot and become fertility"* V1_19). Where soil and water conservation techniques were concerned, terracing (14%) was widely reported as important in maintaining soil fertility by preventing soil erosion (10%). In particular, farmers associated terraces with 'keeping moisture' in soil. The role of terraces in retaining manure and chemical fertilizer was also rarely mentioned (2%, *"Terrace keeps wet and manure. There is no soil erosion because of terrace"* (V2_25)). One farmer's answer acknowledged the role of applications of organic matter in increasing WHC (*"Manure remains water"* V1_29).

In the mental model of low fertility soil, farmers focused on lack of household money (2%) or manure (4%) as the main constraints on soil improvement (4%), and especially their inability to construct or maintain terracing (9%). Farmers suggested that inadequate terracing on sloped fields facilitated soil erosion during the rainy season (7%), leaving behind stony soils. The lack of tillage (2%) was considered the reason for 'hard (compacted) soils' (7%) ("*No tillage makes hard soil because no time for all fields to manage."* V2_22).

3.3. Role of location in farmers' mental model

The specific geographical location and topography of fertile soils were understood to affect water availability. Within the study area, fields around the homestead (14%) or close to rivers (19%) were

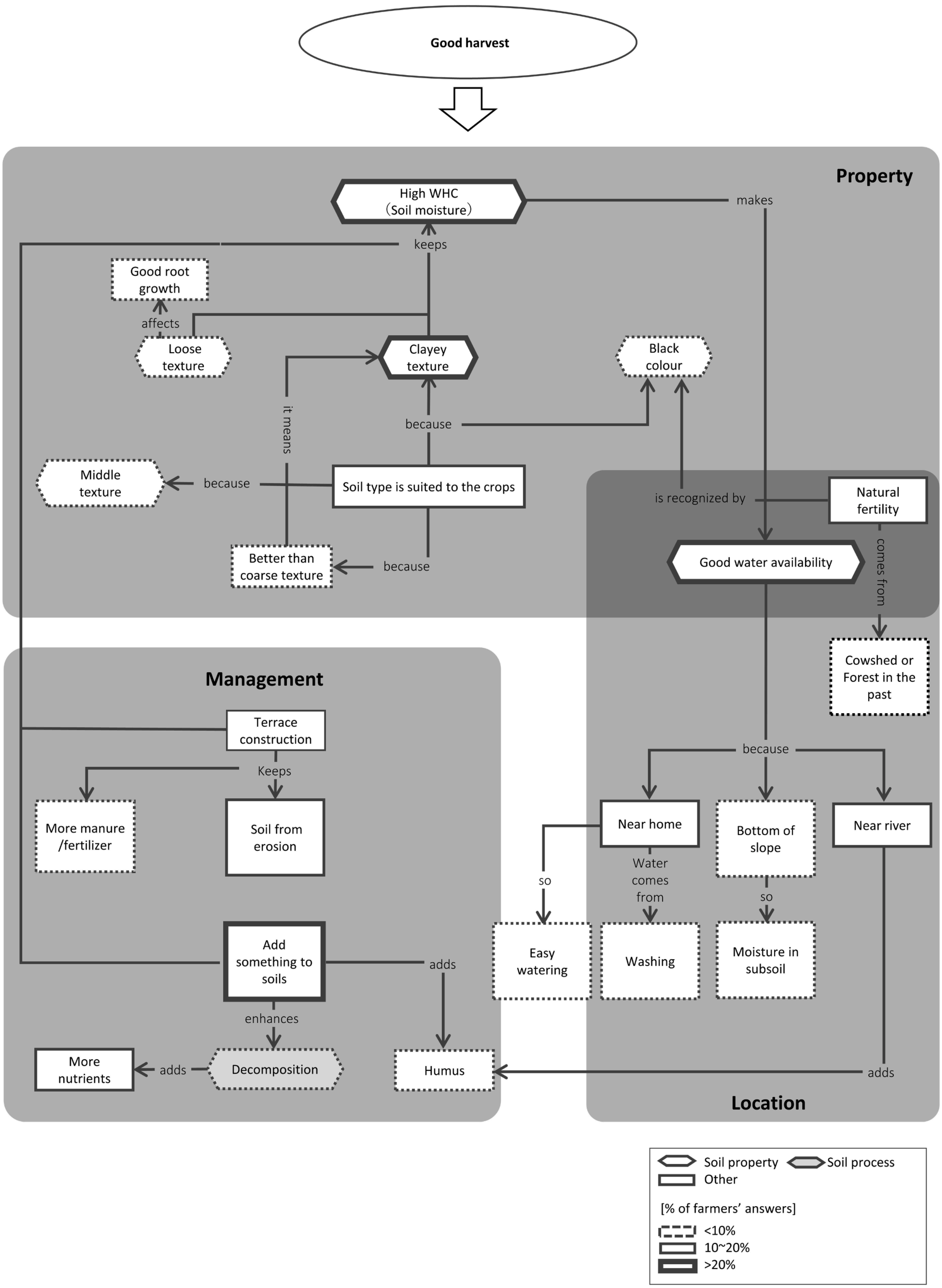

Fig. 1. Mental model of fertile soil by Kitui farmers ($n = 58$, source: causal diagram with Kitui farmers, August-September 2016).

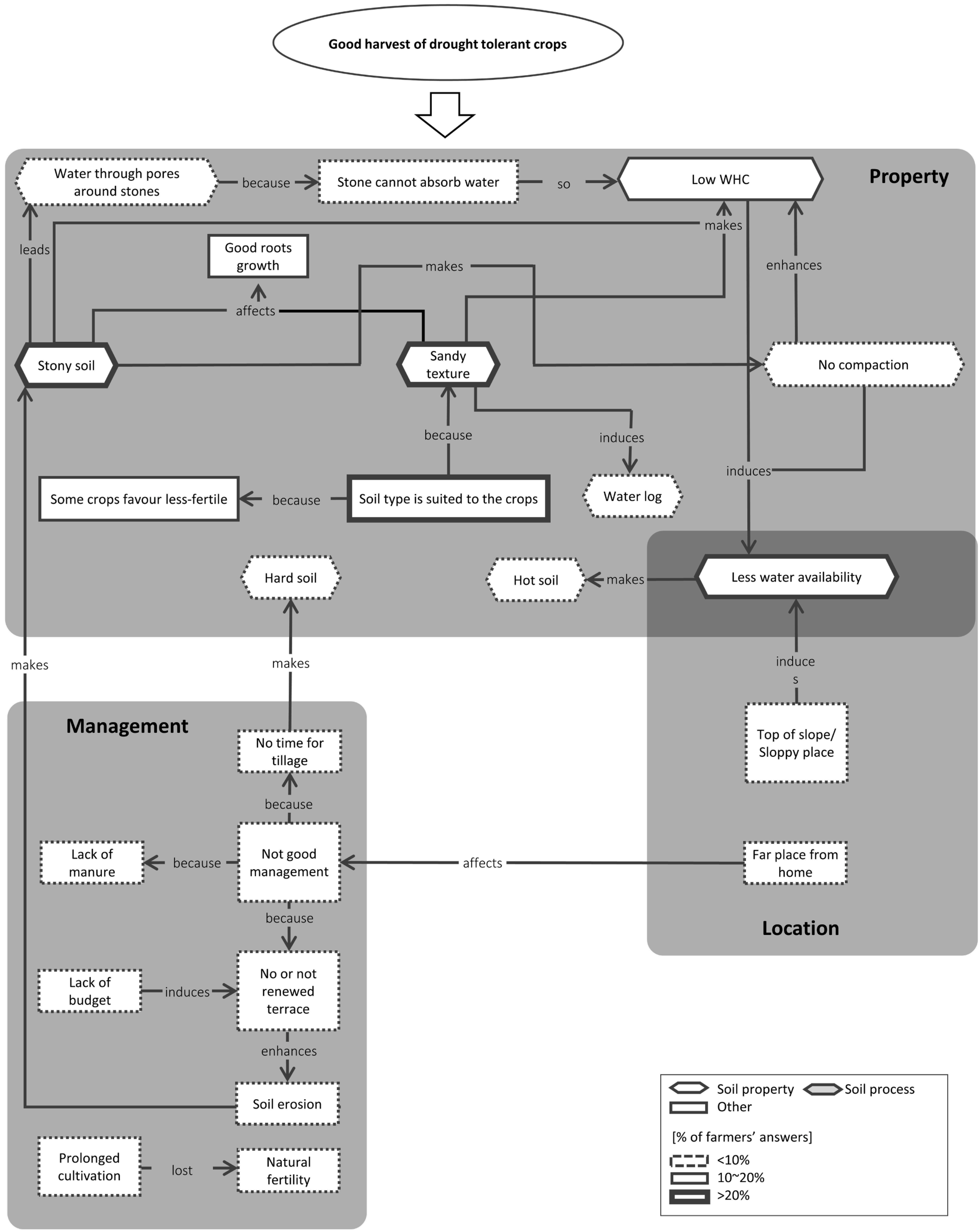

Fig. 2. Mental model of low fertility soil by Kitui farmers ($n = 56$, source: causal diagram with Kitui farmers, August-September 2016).

Table 1
Share of key concepts per village for fertile and low fertility soils (n = 58 and 56, source: structured interview with Kitui farmers, August-September 2016).

Category	Concept		Fertile soil Village Village1 (%, n = 29)	Village2 (%, n = 29)	Total (%, n = 58)	Low fertility soil Village Village1 (%, n = 29)	Village2 (%, n = 29)	Total (%, n = 56)
Property	WHC	High	14	34	24			
		Low				7	17	13
	Water availability	High	10	45	28			
		Less				26	62	45
		Texture	Clayey	17	31	24		
			Loose	0	14	7		
			Middle	7	3	5		
			Sandy			56	62	59
	Black color			3	7	5		
	Hot soil					0	14	7
	Hard soil					7	7	7
	No compaction					7	0	4
Process	Decomposition		3	0	2			
	Water through pores around stones					0	7	4
Management	Add something to soil		69	21	45			
	Lack of manure					4	3	4
	Humus		0	7	3			
	Terrace	Construction	10	17	14			
		No or not renewed				0	17	9
Location	Near river		0	38	19			
	Home	Near	14	14	14			
		Far				4	0	2
	Slope	Bottom	0	14	7			
		Top				0	14	7

considered the locations where the wettest and therefore most fertile soil was normally found. Farmers explained the location near home was supplied water from domestic waste from washing (2%) and watering (5%). Humus was accumulated through flooding near the rivers (3%). The bottom of slopes (7%) was also mentioned with moisture in subsoil (7%). The term 'naturally fertile' (14%) where crops grew well without additional inputs was recognised in places where a forest had been in the recent past, but also in areas where cattle had been kept, with high concentrations of additional manure and leaf mold (5%, *"The fertility of soil came from forest which is the original vegetation of this place"* V1_8).

For low fertility soil, a few farmers noted that the tops of slopes had less soil water available to crops (7%). Some farmers needed to walk long distances to their fields, which was perceived as a reason for poor management (2%).

3.4. Differences between villages

The farmers in Village 1 where near the town were intensely focused on the importance of soil amendments and organic and chemical fertilizer (69%) (Table 1). For low fertility soil, their answers were dominated by coarse texture (56%). The only farmer who mentioned the soil process of decomposition was in Village 1. Advantage of location near home for better soil fertility was recognized equally in both villages but the disadvantage of a plot far from home was mentioned in Village 1. The farmers who lived in Village 2 where far from the town gave more answers about soil physical processes than those in Village 1. The farmers who mentioned the soil process of infiltration were also in Village 2 (7%). the importance of terrace construction and the existence of humus were also dominated by Village 2 farmers (17%). The answers on the topographical features (near rivers (38%) and at the bottom and top of slopes(14%)) were taken in Village 2. One farmer from each village mentioned the lack of manure as a reason why they could not do manure application.

4. Discussion

This section considers the portrayal of soil fertility knowledge by farmers in a semi-arid area of Kenya by mental mapping, with an examination of the different perception of fertile and low fertility soils, the way to improve soil fertility and the roles of location. Knowledge gap among villages and individual farmers were discussed and the potential of enhancing soil knowledge exchange between farmers and soil scientists for sustainable soil fertility management is also considered.

4.1. Insights into farmers' soil fertility knowledge through mental mapping

The application of the mental mapping approach (Prager and Curfs, 2016) in the context of the Global South in general, and Kenya in particular, offers a new insight into farmers' soil fertility knowledge. While farmers' mental models for soil fertility were constructed by soil properties, soil management and location, it was the holistic and contextual way in which they used various types of information surrounding soils based on their daily experiences (Wawire et al., 2021). The three thematic areas were voluntarily answered by farmers and it implied that they are the main concern by farmers for soils; "What kind of soils?", "How to improve it?" and "Where is it?". Holistic farmers' soil knowledge was also observed in other Sub-Saharan Africa (SSA) countries (e.g. Buthelezi-Dube et al., 2020). The interview data revealed that Kitui farmers focused on different aspects of fertile and low fertility soils. Plant behavior is an important indicator of soil fertility by farmers. Duvall (2008) emphasizes the fact that in Mali, farmers consider their local soil classification as a combination of local plants and soil types. Weed species are indicators of farmers' soil evaluation in Kenya (Mairura et al., 2007; Wawire et al., 2021). Instead of natural vegetation, the results show the farmers' clear evaluation of suitable crops for each soil.

Farmers placed different emphasis on the three categories when characterizing fertile or low fertility soil. In soil properties, 'water availability' was a key concept in structuring both models. Good water availability was described as a combination of favourable locations and the soil's good WHC, that was associated with a clayey texture, since clay provide increased water retention (Brady and Weil, 2016). In contrast, coarse textured soils allowed rapid drainage with lower WHC and were perceived to be of low fertility, although drought tolerant crops were able to grow in them. Texture was also a main indicator of local soil classification in this area (Yageta et al., 2019), implying that water availability was a limiting factor on agricultural production in Kitui county, which faced the problem of limited precipitation. Drought and water limitation were also key aspects of crop production in SSA (Buthelezi-Dube et al., 2020; Wawire et al., 2021).

The perceived differences between fertile and low fertility soil implies that farmers consider fertile soil as a resource that can be improved by management including amendments application and terrace construction. They decide which plots to improve by adding more manure, fertilizers, and labor for improvement. The decision for amendment application was dependent on farmers' choices; some selected good soil to increase fertility still further, and others chose to improve poor soil. However, Kitui farmers mainly added soil amendments in fertile places because cash crops are planted fertile soils and they want to increase the yields of cash crops more than drought tolerant crops on low fertility soil. Bringing manure to the field near home where is the main location of fertile soil is easier than the field far from home. A similar trend was observed in other counties in Kenya by Murage et al. (2000). Tillage was considered as an important management not to make hard soil in Kitui and the hardness of soil is related to the low organic matter content and 2:1 type clay (Yageta et al., 2019). It is a common idea from farmers while scientists in recommending minimum tillage for conservation agriculture (Halbrendt et al., 2014; Lalani et al., 2021).

The location of the plots was also important for Kitui farmers' soil fertility management. Soil surrounding the home had more frequent opportunities for intended (irrigation and application amendments) and non-intended (inflow from homestead) supplies of water and nutrients. In contrast, if low fertility soil was far from the home, this became a reason for it to receive less attention. The pattern of soil fertility was therefore crucial in determining planting strategies for different crop varieties across the whole farm.

The different perception of soil fertility was recognized among the farmers. Even though they belonged to the same ethnic group, the farmers in the two study villages differed in their focus on soil fertility. Farmers in Village 1 where near the town center emphasized the importance of adding something to soil to increase its fertility, but Village 2, a remote area, farmers mainly focused on water availability and terrace construction. This reflected the availability of agricultural information and access to an agricultural extension worker in Village 1 and the availability of land in Village 2. The positive effects of extension services in providing soil science-based knowledge and the use of new materials (e.g. chemical fertilizer) is well known (Spurk et al., 2020) but in Village 2, it was difficult to communicate with extension officers (Yageta et al., 2019). In contrast, land is more difficult to acquire, buy or rent in Village 1 because of the area's higher population density, since it is nearer to the town (The County Government of Kitui, 2014). The availability of black clay soil near the river, made by alluvial deposits, is dominant in Village 2 (Yageta et al., 2019). Therefore, for farmers in Village 1, the improvement of soil near the homestead would be the top priority and if they have an away field in a remote place, the comparative lack of attention would made difference in soil fertility. In Village 2, the availability of different type of soil would increase the farmers attention on soil water movement and would induce the creation of detailed knowledge of soil physical properties even with the lack of extension services.

Individual farmers differed in their knowledge of relationships between soil processes and properties. Many were able to articulate a relationship between texture and water, through drainage, wet soils and plant rooting systems, showing understanding of soil's physical process. Farmers explicitly described infiltration, and one farmer mentioned decomposition. They focused mainly on the visual and physical properties of soils and their association with crop yield as the ultimate measure of fertility (Wawire et al., 2021). The farmers' experimental knowledge enables them to see and feel how long water is retained within the soils on their fields after rainfall. Kitui farmers said that they could observe the wetness of soil by touching it with their hands; they understood that clayey soil kept moisture longer than sandy soil (personal communication with Kitui farmers). By contrast, the connection between organic matter and water availability was rarely explained by farmers. An important soil process, decomposition, was also mentioned by only one farmer. This may be because the amount of organic matter was limited in this area, as in other locations in Kenya (Gicheru, 2012), and farmers relied on animal manure rather than leaf mold as an organic fertilizer; consequently, they lacked observational experience of decomposition and its effect on water retention. They placed less emphasis on the processes or mechanisms producing fertility within the soil. This is related to the strong tendency for farmers' soil knowledge systems to accumulate 'know-how' of their field management, contrasting with scientists' focus on the 'know-why': what happens within the soil (Ingram, 2008).

Nevertheless, a small number of Kitui farmers described the connection between organic matter and decomposition, organic matter and WHC, and porosity and infiltration. This implies that Kitui farmers have a knowledge system that relates to understand about soil process within soil science, and could share knowledge in a co-learning approach to soil improvement.

4.2. Practical use of mental model approach for improved knowledge exchange with farmers

The Kenyan farmers' mental models provided clear visualizations of their perception of soil fertility. This research revealed that farmers' knowledge systems have similarities with soil scientific information, especially the relationship between soil physical properties and water retention. Understanding soil scientific information is useful for farmers because it explains their own experiences of how the soil supports crop production through water movement (storage, drainage and supply to plants) and how soil amendment provides nutrients for plants thorough decomposition (Pincus et al., 2018).

Texture and water were key concepts in farmers' mental models; these soil properties can be used as entry points for improved two-way communication between farmers and soil scientists, to co-develop a hybrid form of knowledge. Since visual features are well understood by farmers, the use of visual images (Neset et al., 2019) and videos (Fry and Thieme, 2019) within participatory extension programmes, such as used in many Farmer Field School (FFS) approaches (Ongachi et al., 2018) would be useful. Global Soil Doctors Programme (http://www.fao.org/global-soil-partnership/pillars-action/2-awareness-raising/soil-doctor/en/) initiated by the Food and Agricultural Organization (FAO) is another example of the use of visual material explaining the role of soil as a discussion tool for working with farmers to maintain sustainable fertility.

The validation that differences in perceptions depended on location and individuals also emphasizes the importance of understanding how environmental and social aspects working to increasing the suitability and sustainability of partnership project between farmers and other stakeholders (Kansiime et al., 2021). Working within local farmers' knowledge systems is also important for planning site-specific projects since every location has unique character that are reflected in lived farming experience. Developing holistic frameworks of soil knowledge with farmers is vital to this process, including sharing mental models of each stakeholder, follow up validation or feedback on language, tools and practice, to improve genuine two-way communication and facilitate social learning (Lie and Servaes, 2015; Krzywoszynska, 2019).

With understanding of local farmers' perceptions and demands, the outcomes of scientific studies and development projects may be better suited to local context and different farmer needs. Barrios and Coutinho (2012) argued that seeking a balance between scientific precision and local relevance can help to expand shared knowledge and generate new, hybrid knowledge or knowledge systems. The combination of farmers' 'know-how' and soil scientists' 'know-why' knowledge (Ingram, 2008) through knowledge exchange has improved soil management plans within semi-arid systems in SSA. This can help farmers to choose options appropriate to their current and future situation. The results from this study will be shared with farmers who participated in the work within Kitui County for dissemination among them. The communication challenge here is if farmers understand the contents of their and soil scientists' mental models of soil fertility. Further work is needed to explore how farmers can use mental models and how useful this tool is for them directly. The feedbacks from the farmers will add new insights for the use of mental models for knowledge exchange.

5. Methodological reflections

This research applied the mental model to farmers in the context of one specific area in a county. Farmers' knowledge of soil is constructed holistically, and based on their experiences and environment (Barrera-Bassols & Zinck, 2003), so their perception of fertile soils will change in different environments and soil conditions. Further work is needed to compare the mental models of farmers in different regions and climatic zones, in order to consider not only the difference between farmers and soil scientists, but also the differences among farmers working in different locations and environments. For example, comparison between views on tillage in this research and in Prager and Curfs (2016) reveals that Andalusian farmers focus on its role in weeding, while Kitui farmers focused on the improved 'softness' of the soil. Comparisons between farmers' mental models in other locations would improve understanding of the basis and extent of farmers'' knowledge, and the underlying reasons why farmers make soil management decisions.

6. Conclusion

The creation of mental models was a useful method of visualizing the Kenyan farmers' understanding of fertile and low fertility soils. The importance of WHC, texture, location and use of organic and chemical amendments to their mental model was revealed in this research. By creating aggregated mental models of farmers, the difference in perception among farmers and between villages in the same ethnic group was also revealed. Although farmers rarely mentioned the relationship between soil properties and processes, some of them gave detailed descriptions of the process of water holding, infiltration and nutrient accumulation and decomposition. As farmers already used texture and visual assessments of soils used by soil scientists, using visual materials including mental models for the communication of soil scientific knowledge to farmers would enhance their understanding. This additional knowledge could enable them to improve hybridised knowledge systems that support site-specific decision-making and lead to suitable and sustainable soil fertility management.

Declaration of Interest

I confirm that this is my own work and the use of all material from other sources has been properly and fully acknowledged. The authors have no conflicts of interest directly relevant to the content of this article.

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