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UNDERSTANDING PLURALITY IN SOIL FERTILITY KNOWLEDGE FOR ENHANCED SCIENCE-FARMER COMMUNICATION A CASE STUDY IN KENYA

Thesis resubmitted for the degree of Doctor of Philosophy

School of Agriculture, Policy and Development

YOSHIE YAGETA

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Declaration of original authorship

I confirm that this is my own work and the use of all material from other sources has been properly and fully acknowledged.

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Yoshie Yageta

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Abstract

Sustainable soil management underpins many of the UN Sustainable Development Goals (SDGs). Knowledge exchange between farmers and soil scientists or extension officers is essential to create hybrid knowledge for sustainable soil fertility management under climate change. However, miscommunication between them and the unequal distribution of information reduce both the absorption of information and its implementation for soil management. Studies that provide thorough examinations of farmers' knowledge systems about soil fertility, the effect of the difference of content and sources of information, and the effects of external and internal factors, including determinants of intentions for farmers' soil knowledge construction and its implementation, are still rare. Therefore, this study's aim was to explain how the construction of farmers' knowledge of soil fertility compares to soil scientific knowledge of fertility and how the farmers' knowledge system is used for land management. The aim is divided into three main objectives: to examine the similarities and differences between farmers' qualitative evaluation and soil science quantitative analysis for soil fertility classification; to explore farmers' and scientists' mental models of soil fertility and the relationship between soil properties and processes for communicating soil knowledge; and to explore how cropping and land management responses to climate variability and soil type are shaped by perception of risk, individual motivation and perceived capacity. Empirical fieldwork was carried out in two villages in Kitui County, Kenya, in 2016 to compare the effect of location on the construction and implementation of soil knowledge. Structured questionnaire interviews, participatory methods and focus group discussion involving 60 farmers, two extension officers and eight soil scientists (in Wageningen) were used for social and soil knowledge data collection. 116 soil samples were taken from the places with the most and worst fertile soils from farmers' fields, according to the farmers' perceptions, and their physiochemical parameters were analysed. This study revealed the importance of soil texture and colour in both soil scientific and local soil classification: although the farmers did not use scientific methods or terminology, they were aware of a significant relationship between the amount of nutrients and water holding capacity (WHC). The location of soils and previous soil degradation affected the farmers' knowledge construction. The mental models clearly showed that farmers' perception of soil fertility was focused on WHC, manure and fertilizer application, and location. Different perceptions of soil processes also appeared, both among farmers and between farmers and soil scientists. Farmers' crop selection and timing of seeding differed according to livelihood strategy, soil type, water availability and the occurrence of drought events. Communication with extension officers increased their adoption of innovations. Based on the results, this study recommended the development of a hybrid communication approach in order to co-learn with farmers and accelerate communication among stakeholders, with the goal of creating hybrid knowledge for site-specific sustainable soil management.

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List of Acronyms

AEZ: Agro-Ecological Zone

AIS: Agricultural Innovation System

AKIS: Agriculture Knowledge and Information System

AKS: Agricultural Knowledge System

AP: Available Phosphorus

ATIRI: Agricultural Technology and Information Response Initiative

CEC: Cation Exchange Capacity

EC: Electrical Conductivity

E-E: Entertainment Education

GLM: General Liner Model

HDI: Human Development Index

IPCC: Intergovernmental Panel on Climate Change

IFNA: Initiative for Food and Nutrition Security in Africa

KARI: Kenyan Agriculture Research Institute

KARLO: Kenya Agriculture and Livestock Research Organization

NALEP: National Agriculture and Livestock Extension Programme

NACOSTI: National Commission for Science, Technology and Innovation

NGO: Non-Governmental Organization

NN: Nitrate Nitrogen

OM: Organic Matter

FFS: Farmer Field School

PPP: Purchasing Power Parity

SATREPS: Science and Technology Research Partnership for Sustainable Development

SCT: Social Cognitive Theory

SDGs: UN Sustainable Development goals

SRA: Strategy to Revitalize Agriculture

SSA: Sub-Saharan Africa

TOC: Total Organic Carbon

ToT: Transfer of Technology

TPB: Theory of Planned Behaviour

TRA: Theory of Reasoned Action

T&V: Training and Visit

TN: Total Nitrogen

WHC: Water Holding Capacity

WRB: World Reference Base

1. Introduction

1.1. Research background and rationale

Sustainable soil management underpins many of the UN Sustainable Development Goals (SDGs), particularly those supporting food production systems with which to deliver 'zero hunger' (UN, 2015). Farmers in Sub-Saharan Africa (SSA) face a range of risks to their agricultural production and must manage a process of deciding what are acceptable trade-offs in responding to these risks, balancing limited resources, such as labour, seed, inputs, variable soils, and environmental outcomes, household needs, and social and cultural roles (Alliance for a Green Revolution in Africa (AGRA), 2013; Oldeman et al., 1991). 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 et al., 2018). Criticism of the limited effectiveness of implementing top-down technology and scientific information transfer including soil science knowledge through extension services has led to increasing attention towards the value and integration of indigenous knowledge held by farmers (Barrios and Trejo, 2003; Berazneva et al., 2018; Guzman et al., 2018; Richelle et al., 2018). Improving communication and the share of sustainable soil management is needed in order to face global challenges of climate, water and food security (Godfray et al., 2010).

Mutual understanding between farmers and scientists is not easy due to the ways in which indigenous 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 in crop growth, each knowledge system has gaps and these are complemented by each other. For soil scientists, better communication with other non-academic stakeholders can bring challenges that often result from dissonance caused by not understanding each other (Ramisch, 2014). Seeking a balance between scientific precision and local relevance expands shared knowledge to generate a new, hybrid knowledge system (Barrios et al., 2006). Beyond only describing indigenous soil taxonomy, the understanding of social and environmental contexts of farmers' soil fertility evaluation has been needed (Niemeijer and Mazzucato, 2003; Okpara et al., 2018). In addition to soil knowledge, other social and environmental factors affect farmers' decision-making process (Ajzen, 2002; Adger et al., 2009).

Previous ethnopedological studies have revealed a correlation between indigenous soil fertility evaluation and soil scientific analysis (Barrera-Bassols and Zinck, 2003; Kamidohzono et al., 2002; Osbahr and Allan, 2003; Berazneva et al., 2018). However, the key underpinnings of indigenous knowledge systems, including the effect of the location of soils with 'good' or 'bad' fertility, along with social and environmental perceptions and historical background in the community, have seen limited discussion. Understanding the correlation of farmers' qualitative evaluation and soil science quantitative analysis of soil fertility would connect to the creation of local tailor-made soil assessment systems so as to suit each regional characteristic.

For a better mutual understanding of soil fertility perception by farmers and soil scientists, a visualisation method - the creation of mental models - was used by Prager and Curfs (2016) for farming systems in Spain. Visualisation of different soil knowledge systems has rarely been carried out and it makes it easy to compare the different knowledge systems for the acceleration of mutual understanding and two-way communication.

In addition to the perception of soil fertility, the role of complexity in perceptions of risks to agricultural production (Ovuka and Lindqvist, 2000; West et al., 2008) and the implications for decision-making and practice between farmers when managing environmental risk (Ghadim et al., 2005; Rao et al., 2011; Tanaka and Munro, 2014) have been debated. However, a holistic understanding, including the identification of cropping and land management responses to climate variability and perceived soil fertility and local soil classification, individual motivation and perceived capacity, and how these can reinforce livelihood pathways for different farming households, has rarely been shown. Adopting the three determinants of intention from the theory of planned behaviour (TPB) (Ajzen, 1991) as a conceptual lens helps to explain patterns of decision-making.

The following are needed: 1) revealing background information, 2) visualisation, and 3) observation of the relationships with land management of indigenous knowledge systems for soil fertility. In this thesis, research was conducted to assess how the perception of soil properties by farmers contrast with technical soil fertility evaluation, how the perception affects decision-making in respect of land management and what are major factors for their management decisions. Revealing them would improve future communication between scientific and indigenous knowledge systems to deliver space for the creation of hybrid knowledge for sustainable soil management practices.

1.2. Personal motivation

Through Graduate and Master studies at the University of Tsukuba (under the supervision of Prof. Teruo Higashi) on soil salinization in the Nile Delta in Science and Technology Research Partnership for Sustainable Development (SATREPS), i.e. “Sustainable Systems for Food and Bio-energy Production with Water-saving Irrigation in the Egyptian Nile Basin”, in 2010–2013, as well as work experience in the Gaza Strip (Palestine) as a Non-Governmental Organization (NGO, Champaign for the Children of

Palestine) staff member for "Empowerment of the Agriculture Sector, Training and Promotion of Ecological and Sustainable Methods in the Gaza Strip" in 2013–2014, I felt the need to include farmers' voices in research and development projects in order to increase the efficiency and adaptability of agricultural extension projects.

In addition, between Dec. 2010 and Jan. 2011, I undertook a research internship at the Bioversity International Nairobi office under the JAPAN-CGIAR Fellowship Program "Assessing major determinant factors that influence soil chemical properties in Kitui County, Kenya". The supervisors were Dr Yasuyuki Morimoto and Dr Patrick Maundu. The research was based on their previous project entitled "Managing agricultural biodiversity for better nutrition and health" (Dietary Diversity Project) in the Kitui District. During the research they recognised that Kitui farmers traditionally planted many kinds of crops on various kinds of soils for their food security. Although the objectives of my internship research concerned the identification of 1) major factors influencing soil chemical properties and 2) the relationship between agro-diversity (number of crop varieties) and soil nutrient status, they were inconclusive during the two-month survey. However, variations of soils, crop performance and management practices were seen during the field survey. Therefore, I increased my personal motivation to study more and conduct scientific analysis of Kitui farmers' knowledge of soil and its implementation.

1.3. Aims and objectives

Aim: To understand how the construction of farmers' knowledge of soil fertility compares to soil scientific knowledge and how the farmers' knowledge system is used for land management.

Objective 1: To examine the similarities and differences between farmers' qualitative evaluation and soil science quantitative analysis for soil fertility classification

- What are the similarities and differences between farmers' qualitative evaluation and soil science quantitative analysis of soil fertility and soil classification?
- How does the location of soils (e.g. villages and distance from home) influence farmers' evaluation of soil fertility?

Objective 2: To explore farmers' and scientists' mental models of soil fertility and the relationship between soil properties and processes for communicating soil knowledge

- Is it possible to create mental models of soil fertility, within a mixed cropping and livestock farming system with a semi-arid climate, for farmers and scientists by considering what makes soils fertile?

- What are the differences in knowledge of soil fertility among farmers?
- What are the synergies and differences between farmers' and soil scientists' mental models of soil fertility?

Objective 3: To explore how cropping and land management responses to climate variability and soil type are shaped by perception of risk, individual motivation and perceived capacity.

- What are the dominant livelihood strategies and farming systems for different farming households?
- How does intra-annual climate variability change these narratives, for example, under drought or wetter conditions?
- How do information sources and communication with extension officers and among farmers affected for changing farmers' soil management pattern?

1.4. Structure of the thesis

This thesis is presented as a series of academic papers. Chapter 1 shows the setting context and the research theme of the thesis. Chapter 2 presents a literature review of the history and current debates surrounding ethnopedology and the utilisation of indigenous knowledge for agricultural development. The research gap and the conceptual framework show the position of this thesis in the debate. Chapter 3 shows the methodology and information on two study villages. Chapters 4 to 7 present the results from this research, addressing each objective in turn. Chapter 4 is concerned with "*Comparing farmers' qualitative evaluation of soil fertility with quantitative soil fertility metrics in Kitui County, Kenya*" (Objective 1). This paper was published on *Geoderma* in March, 2019 (volume 344, p. 153-163, Appendix 1). Chapter 5 and chapter 6 concern "*farmers' and scientists' mental models of soil fertility and the relationship between soil properties and processes for communicating soil knowledge*" (Objective 2). Chapter 5 is focus on Kitui farmers' mental model for soil fertility perception and chapter 6 shows the soil scientists' mental model and discuss the comparison with farmers' one. The content of chapter 5 is in preparation for submission to *Soil Use and Management*. Chapter 7 features "*Rural livelihood diversification and decision-making for soil and climate variability management in Kenya*" (Objective 3). This paper is in preparation for submission to *Journal of Soil and Water Conservation*. Chapter 8 concludes this thesis, drawing together all key findings and assessing how the research meets the stated aims. Implications for further research, policy and programmes for sustainable soil fertility development are considered.

2. Literature review

2.1. Introduction

This research is theoretically situated within the conceptual interface between soil science and agricultural development. In order to explore how ideas within this conceptual interface frame this research study, section 2.2 will first examine the concept of sustainable development and highlight its important relationships with soil security to explain the underpinning positionality of the research. This is followed by three focused conceptual sections that reflect ideas that are engaged with throughout the research. These are: (1) an examination of current understanding of different types of soil knowledge, and the importance of recognising scientific and indigenous knowledge (section 2.3); (2) an review of the main ideas within understandings of communication and knowledge exchange, particularly in relation to how soil knowledge is shared (section 2.4); and (3) a summary of the key dimensions of decision-making, specifically how knowledge about soils that has already been developed is then used to inform action (section 2.5). Finally, in section 2.6, these central research ideas are connected and summarised through a conceptual model for the purpose of ordering the research approach, and highlighting the key research gaps. Specific terms that are used throughout the thesis are defined below in Table 2-1.

Table 2-1 Definition of terms

Concept	***Term***	***Definition***
Soil knowledge	Hybrid knowledge	*"*Knowledge generated through a process that facilitates the integration of local (indigenous) and technical (scientific) knowledge*"* (Barrios and Coutinho, 2012: 66)
	Ethnopedology	A study field that "aims to document and understand the local approaches to soil perception, classification, appraisal, use and management" (Barrera-Bassols and Zinck, 2003: 172)
	Scientific knowledge	Knowledge involving western technology or techniques (but there exists no concise definition of the latter) (Mercer et al., 2010). A fundamental presupposition of Eurocentric science is that nature is knowable; 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	"A body of knowledge existing within or acquired by local people over a period of time through accumulation of experiences, society-nature relationships, community practices and institutions, and by passing it down through generation" (Brokensha et al., 1980: 13). 'Indigenous knowledge' and 'traditional knowledge' are often used as synonyms (Sillitoe, 1998).

Concept	*Term*	*Definition*
Soil knowledge	Fertile Soil as a scientific term	"A soil that is fertile enough to provide adequate root depth, nutrients, oxygen, water and a suitable temperature and no toxicity" (Wild, 2003: 51).
Communications and knowledge exchange	Agricultural Knowledge System	"A system of beliefs, cognitions, models, theories, concepts, and other products of the mind in which the (vicarious) experience of a person or group with respect to agricultural production is accumulated" (Röling,1988: 33)
	Agricultural Information System	"A system in which agricultural information is generated, transformed, transferred, consolidated, received and fed back in such a manner that these processes function synergistically to underpin knowledge utilization by agricultural producers" (Röling,1988: 33).
	Agricultural Knowledge and Information System (AKIS)	"An Agricultural Knowledge and Information System for Rural Development links people and institutions to promote mutual learning and generate, share and utilize agriculture-related technology, knowledge and information. The system integrates farmers, agricultural educators, researchers and extension workers to harness knowledge and information from various sources for better farming and improved livelihoods" (FAO and World Bank, 2000: 2)
Decision-making	Decision-making	The process of making important decisions (Trumble and Stevenson, 2007)
	Social Cognitive Theory (SCT)	A theory that a decision is based on three components: environment, person (cognition) and behaviour, leading to a recursive determination (Muro and Jeffrey, 2008)
	Theory of Reasoned Action (TRA)	A theory that the main factors affecting behaviour are the intention to act; how hard people are willing to try (Ajzen, 1991)
	Theory of Planned Behaviour (TPB)	A theory based on TRA, including three conceptually independent determinants of intention: 'personal attitude', 'subjective norms' and 'perceived behavioural control' (Ajzen, 1991)
	Personal attitude	A person's evaluation for behaviour (favourable or non-favourable to act) (Ajzen, 1991; Paassen, 2004)
	Subjective norms	Social factors that place social pressure on decision-making (Ajzen, 1991; Paassen, 2004)
	Perceived behavioural control	Confidence in a person's capacity, reflecting past experience (Ajzen, 1991; Paassen, 2004)
	Adoption	Choosing to take up, follow, or use something (Trumble and Stevenson, 2007)
	Adaptation	A process, action or outcome in a system to better manage or adjust to a change or difficulty (Smit and Wandel, 2006)
	Adaptation capacity	Determinants of the quickness and quality of an adaptation process or action (Smit and Wandel, 2006)
	Innovation	An idea, practice, or objective that is perceived as new (Rogers, 2003)

2.2. Sustainable development and soil security

The term 'Sustainable Development' is widely used, and was the main theme of the 'Rio Declaration on Environment and Development' at the United Nations Conference on Environment and Development (UNEP, 1992). The idea was also embedded in the Millennium Development Goals (MDGs) (UN, 2000) and SDGs (UN, 2015). However, this term has a complex meaning that has been interpreted in different ways by different actors. This section reflects on how sustainable development is related to concerns about soil security.

For the last few centuries, before the idea of sustainable development was established, the view that humanity could triumph over nature and a Promethean view were widespread. The Promethean idea emerged with capitalism, the industrial revolution and modern science. Environmental problems were treated as local issues. However, the intensification of environmental problems and poverty concerns stimulated other ways of thinking about sustainable life and a greater understanding of the connection between people and nature (Hopwood et al., 2005).

The first use of the term 'sustainable development' was in 1980 in the World Conservation Strategy (IUCN/UNEP/WWF, 1980). The basic concept of sustainable development has been described as a "growing the awareness of global links between mounting environmental problems, socio-economic issues to do with poverty and inequality and concern about a healthy future for humanity" (Hopwood et al., 2005: 39). However, different aspects are emphasized depending on each stakeholder's position. Rees (1995) classified different views into three categories: status quo, reform and transformation, while Hopwood et al. (2005) mapped views according to concerns about equality and environment.

The first category according to Rees (1995), status quo, is the idea that adjustment of the current situation is needed for sustainable development. Its main supporters remain the decision makers in government and businesses, who argue that economic growth is one of the solutions (Hopwood et al., 2005). A well accepted definition of sustainable development provided by Brundland, "meeting the needs of the present without compromising the ability of future generations to meet their needs" (World Commotion on Envirionment and Development 1988: 43), has been generally used from this standpoint. Criticism of the status quo has focused on the lack of consideration for environmental sustainability (Hopwood et al., 2005), and Lee et al. (2000: 32) argue that this idea remains an "unashamedly anthropocentric concept" . The World Bank (2000: 32) have increasing recognised these challenges and have stated that "macroeconomic stability and market-friendly reforms are essential for reducing poverty" and the Real World Coalition, which represents 25 UK campaigning NGOs, claims that economic growth increases the gaps between rich and poor and intensifies environmental degradation (Christie et al., 2001).

The second category is reform (Rees, 1995). Reformers have argued that the current economic system needs change and recommend a shift in policy and lifestyle. They argue that governments should control taxes and subsidies in order to generate incentives to change behaviour. Hopwood et al. (2005) highlight the fact that those who support this idea are mainly academics and NGO experts but the ideas have become increasing popularised and radical.

Awareness of environmental issues were popularised by concerned reformers who gave a high public profile to development debates. In 1972, *The Limits to Growth* (Meadows et al., 1972) was published; the authors warned of risks from continuing economic growth without considering environmental pollution and resource limitation. They argued that degradation of the environment would make human activities exceed sustainable environmental thresholds, and that both ecological and economic stability must be delivered for global sustainability. The Brundland report rejected the opinion that limits to development were technical, cultural and social (World Commission on Environment and Development, 1988; Kirkby et al., 1995). However, the authors of *the Limits to Growth* continued to develop this debate (Meadows et al., 1992); social and psychological factors, such as visioning and networking, were added as important to the term 'sustainable society'. The World Conservation Strategy (IUCN/UNEP/WWF, 1980) suggested optimal use of natural resources for sustainability. In 1991, further emphasis was placed on the importance of behavioural changes by individuals, communities and nations (IUCN/UNEP/WWF, 1991). One criticism has been that the environment achieved too prominent a position when defining sustainability, and other factors must be included in the consideration of acceptable trade-offs: attention must be paid to socio-economics, especially for poor communities (Bullard, 1990). There are different perspectives on the acceptability of the various trade-offs proposed to achieve sustainability; this is illustrated in Figure 2-1 (Moore, 2007). The balance of all three concepts, Equity, Ecology (e.g. soil) and Economy (e.g. farmers' livelihood), is needed for sustainable development. However, potential conflicts between different stakeholders develop multiple visions of sustainable development. This has become a highly topical concern both within the popular media, policy and literature and has raised tensions between different viewpoints (Kanter et al., 2018). This issue of the how different stakeholders develop different perceptions is a key grounding for my study; increasing the sustainability and adaptability of development programmes by increasing mutual understanding between farmers and the other stakeholders is an objective for the research.

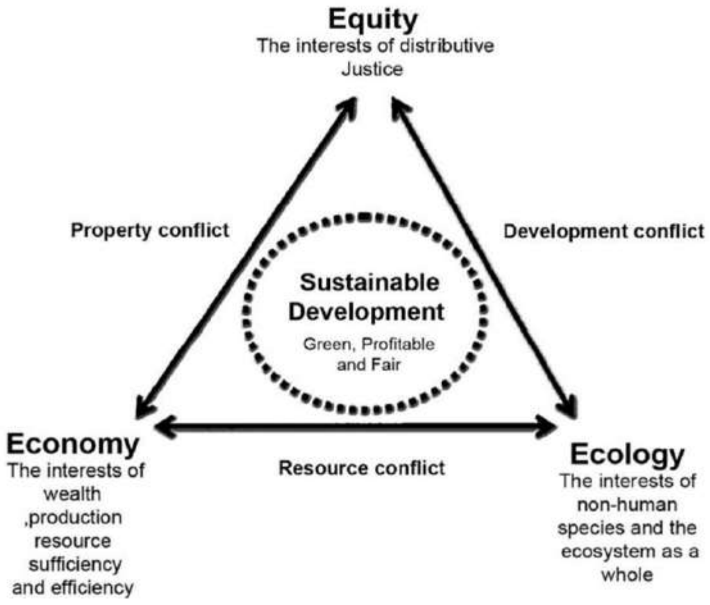

Figure 2-1 Conceptual diagram to illustrate the trade-offs that exist between different priorities of sustainability (Moore, 2007)

The third category is transformation (Rees,1995). Supporters of this idea strongly oppose current economic and power structures and argue that reform is not enough to deliver sustainable development. They argue that greater participation is needed from people remote from the centre of power, such as indigenous groups, the poor, working class and women, for this process to be equitable (Hopwood et al., 2005). There are, however, different ways to transform. Deep ecologists claim that the environment remains critical and social aspects must be managed within these boundaries (Pepper, 1993). By contrast, traditional sociology has focused on social equity (Buttel et al., 2001). As a compromise between these ‘nature first’ and ‘human first’ concepts, eco-socialism (Pepper, 1993) and environmental sociology (Buttel et al., 2001) evolved. From grass-roots activity, environmental justice has arisen: this opposed perceived social injustice, and argued for environmental equality regardless of race, colour, gender and power (Capek, 1993).

Current debates about ‘sustainable development’ have pursued parallel tracks over time (status quo, reform and transformation) due to different opinions of stakeholders, such as governments, industries, ecologists, economists, socialists and citizens. There is no single coordinated approach to sustainable development and this remains an on-going challenge. For example, ‘green growth’ is an increasingly influential idea that seeks to combine both technological transformation and conservation of the natural environment in its development strategy (World Bank, 2011). Likewise, the current Sustainable Development Goals (SDGs) have sought to address these pluralized aspects of development issues as 17 distinctions but interlinked each other. Within these, soil security is identified as a vital component of sustainability (Goal 15: 'Life and Land'). Sustainable soil management also supports food production systems, needed to deliver Goal 2: 'Zero Hunger' (UN, 2015).

This study focuses on 'soil security' because, as the SDGs have identified, soil is the basis of life for both human activity and the natural environment. Soil security is a concept that acknowledges soil's importance to sustainable development, and is related to the management of soil to maintain production of foods and other services (McBratney et al., 2014). This has become a high-profile issue, with the 68th UN General Assembly (2013) identifying 2015 as the International Year of Soils (IYS) to raise awareness and to promote the sustainability of the limited soil resources (UN, 2014).

Soil security remains a contemporary concern, especially in the context of climate change and variability, the growing urban food demand and limited financial resources for extension and innovation (Koch et al., 2013; Fairhead et al., 2017; IPBES, 2018). However, soils have been damaged by desertification, land degradation and drought. It has been reported that 24% of soils in the world's inhabited areas are degraded by human activity (Oldeman, 1992). Sustainable soil management remains a particularly acute challenge across parts of Sub-Saharan Africa (SSA) (Barrett and Bevis, 2015). Agriculture is the main industry and 80% of farmers (85% in Kenya) depend on less than two hectares of farmland for their livelihoods (Alliance for a Green Revolution in Africa (AGRA), 2013). Managing crop performance in SSA is a complex business because there are multiple factors affecting local production, which is characterised by uncertainty in rainfall, crop pests and volatile market dynamics (Boko et al., 2007; Hurley, 2010). Current climate change impacts increase the risk of soil erosion damage through runoff and drought (IPCC, 2001; Below et al., 2010), presenting new management challenges for farmers who have often already adapted to farming under existing semi-arid conditions and in areas of marginal soil quality (Boko et al., 2007). Exposure to changing hazards has forced farmers to explore ways to manage these complex predicaments through agricultural innovations, including the use of drought tolerant crop varieties, early planting, soil and water conservation and irrigation (Alliance for a Green Revolution in Africa (AGRA), 2013; FAO, 2019a). In order to maintain soil fertility, small scale farming in SSA must be maintained and improved. While there has been a shift from crisis narratives about poor management, desertification and land degradation in East Africa (Slegers and Stroosnijder, 2008), challenges to soil security remain: the causes arise not only from natural issues, but include growing population and urban food demands, and limitations in the resources available for extension and innovation support (Koch et al., 2013).

The activities of farmers are essential to the achievement of suitable soil management, because farmers are the managers of farmlands. Their knowledge from experience of soils often remains the basis of their management decisions. Therefore, interdisciplinary studies of soil that combine scientific and indigenous views have been explored in order to understand these decisions (Teegalapalli et al., 2018). The study of indigenous soil knowledge, or “Ethnopedology”, aims to document and understand local approaches to soil perception, classification, appraisal, use and management, and studies on this subject have increased considerably since the early 1980s (Barrera-Bassols and Zinck, 2003). The next section explores the understanding of different forms of soil knowledge, in particular the value of comparing scientific soil knowledge, which is promoted as a basis for soil scientists and government and NGO extension work, with the construction of indigenous knowledge of soil, normally based on life experience.

2.3. Conceptualizing soil knowledge

Knowledge is most easily understood as a collection of interconnected schemes of interpretation. By accessing new information, humans can learn to reduce uncertainty and try to bring order to the world around them. “All knowledge systems consist of classifying the world and creating typologies, rules and methods for understanding. They are based on experimentation and innovation” (Davis, 2006: 151). In this study, soil knowledge is classified as two types, soil science knowledge and indigenous soil knowledge, although there are similarities and differences between them. The third way of knowing is a neo-indigenous, which is a combination of indigenous and scientific knowledge (Munyua and Stilwell, 2013). Farmers often combine indigenous and scientific soil knowledge to develop effective farm management.

2.3.1. Soil science

Soil science is one part of Eurocentric science. Scientific knowledge is generally understood to involve western technology or techniques. However, there exists no concise definition of the latter (Mercer et al., 2010). A fundamental presupposition of Eurocentric science is ‘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) through a reductionist approach. Scientific methods of knowing nature involve the testing of ideas or hypotheses through systematic collection and analysis of data on something unknown by experiments or observation. The overarching goal is to unravel the fundamental laws of nature (Motz and Weaver, 1988).

Soil science is considered to be one of the natural sciences, and has its own story of evolution as a discipline over time. Traditionally, soil was considered only as the weathered substances from rocks, and the focus was on its agricultural productivity. By the end of 19th century, Dokuchaev saw soil as a mixture of mineral and organic materials; he stated the effects of organisms, including plants and animals, on soil formation (Vilenskii, 1957). Study fields involving soil have expanded from agriculture (e.g. relationships of nutrient uptake by plants, Hermans et al., 2006) to environmental issues (e.g. biodiversity, Smith et al., 2015).

Soil scientists can be divided into two main types. Pedologists (from ‘pedology’) study “soils as natural bodies, the properties of soil horizons, and the relationships among soils within a landscape” (Brady and Weil, 2016: 14). Edaphologists (from ‘edaphology’) “focus on the soil as habitat for living things, especially plants” (Brady and Weil, 2016: 14). Soil is also understood within the fields of soil physics, soil biology and soil chemistry.

Soil surveys are conducted for two purposes. The first to measure changes in soil properties and test academic hypotheses related to soil formation and/or function, while the second is to obtain a general impression of the soils in the area in order to look at land capability or the opportunities for agricultural production by using a classification system. Academic research is dominated by the first, while the second role is mainly undertaken by governmental organizations and consultation services. Landon (1984) created a generalized lists of soil properties used in soil surveys and classifications and Ashman and Puri (2001) developed a table of these (Table 2-2). Traditionally, the focus has been placed on soil’s physical and chemical properties. In recent years, the interest in soil biology and ‘soil health’ has been based on the idea of the soil as a living system.

Table 2-2 Main observed soil properties on soil survey and classification (adapted from Ashman and Puri (2008) and Landon (1984))

Category	Examples
1. Site details	Location, topography, land-forms, vegetation and land use
2. General soil information	Stoniness, presence of salt
3. Soil morphology	Horizon depths and thickness, moisture status, colour, structure, root size and distribution
4. Field test	Bulk density, pH, textural analysis (finger methods)
5. Laboratory tests	Textural analysis (mechanical analysis), nitrogen concentration, field capacity
6.Specialized information	Climate data

2.3.2. Indigenous soil knowledge

Soil knowledge has also evolved locally as a part of indigenous knowledge. Indigenous knowledge is "*a body of knowledge existing within or acquired by local people over a period of time through accumulation of experiences, society-nature relationships, community practices and institutions, and by passing it down through generation*" (Brokensha et al., 1980: 13). 'Indigenous knowledge' and 'traditional knowledge' are often used as synonyms (Sillitoe, 1998). This research adopts the term 'indigenous' throughout the thesis. The strength of indigenous knowledge is that it is highly localized and draws on the importance of social and legal dimensions (Barsh, 1999). Soil evaluation is not limited to scientific measures, but is also qualitatively understood by farmers (Roland et al., 2018). Soil management is important to the understanding of indigenous knowledge, and farmers use their local soil experience in making everyday land management decisions (Rushemuka et al., 2014; Guzman et al., 2018). Complex pedological wisdom has, for example, been developed for more than 2000 years in China (Chingkwei & Shenggeng, 1990), Egypt (Chadefaud, 1998), India (Abrol, 1990) and Mexico (Williams, 1975).

2.3.3. Comparing and integrating hybrid knowledge systems across science and indigenous knowledge

Many problems in development programmes have arisen because of miscommunications and misunderstandings between farmers and scientists or other stakeholders who have relied on science-based knowledge (Ramisch, 2014). Understanding these dissonances is a necessary first step for any development project (Ramisch, 2014). With understanding of local farmers' perceptions and demands, the outcomes of the scientific studies and development projects would be suited to local needs. Barrios et al. (2006) noted that while farmers' and scientists' knowledge systems share core concepts, such as the role of water for crop growth, both knowledge systems have gaps and these are complemented by each other (Figure 2-2).

Barrios et al. (2006) argued that seeking a balance between scientific precision and local relevance would help to expand shared knowledge and generate new, hybrid knowledge or knowledge systems. Figure 2-2 illustrates a concept that is vital for the construction of this study and for the enhancement of each stakeholder's understanding of sustainable development. Black (2000: 125–126) argued that "while many traditional problems (e.g. pests) may be solved with new methods, new problems, particularly environmental problems, may be best dealt with through a combination of new and traditional extension". In this section, firstly, the similarities and differences between scientific and indigenous soil knowledge are compared, and secondly, the potential of combining the two knowledge by farmers for the management of their fields is explored.

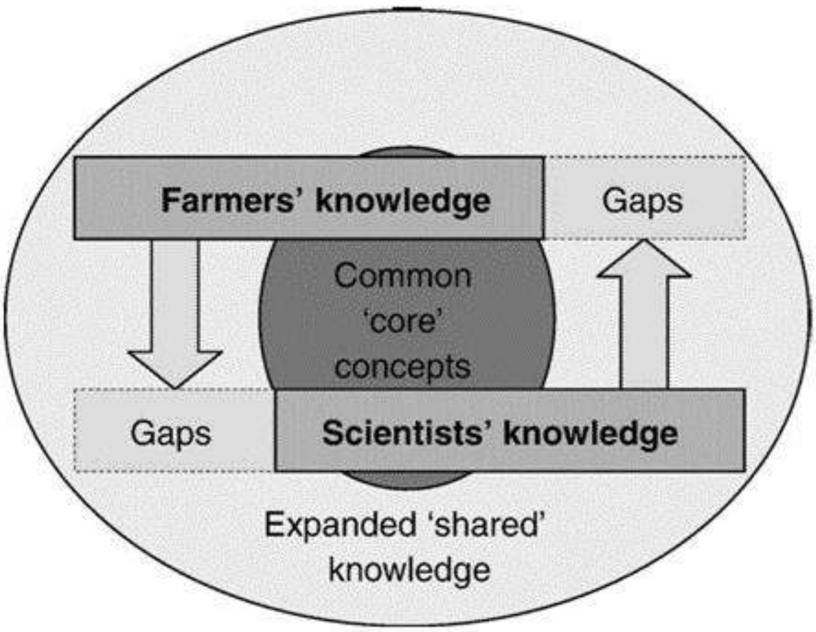

Figure 2-2 Conceptualising an expanded shared knowledge system (Barrios et al. 2006)

Similarities

When both soil scientists and farmers evaluate soil fertility, their focus is same: the performance of crop growth (Murage et al., 2000; Rushemuka et al., 2014). In indigenous classifications, farmers use simple indicators that are visible or easy to evaluate. Physical properties are observed in a similar way to international classification (Table 2-3). Indigenous soil taxonomic systems are developed for each location but there can be universal criteria: colour, texture, consistency, soil moisture, organic matter (OM), stone content, topography and land use are main indicators and are used for more than 40% of indigenous soil taxonomy (Barrera-Bassols and Zinck, 2003). As for the evaluation of productive and non-productive sites in the Central Highlands of Kenya, crop yield, colour, soil tilth, indicator species including weeds and macro-fauna, and soil moisture or water retention were mainly used to classify the differences (Mairura et al., 2007; Rushemuka et al., 2014).

The correlation between indigenous soil evaluation and scientific analysis is clear. Indigenous evaluation of productivity is strongly related to chemical properties, such as the amount of organic carbon and exchangeable cations, and biological properties including biomass value (Murage et al., 2000), and physical properties such as aggregate stability of soils (Mairura et al., 2007). However, there are gaps between the two knowledges. The differences are categorized into six main aspects: perception, soil depth, observation items, spatial scale, timescale and needs.

Table 2-3 Comparison of international and indigenous soil classification systems

International or Indigenous	Reference	Observed Soil Properties			
		Physical	Chemical	Biological	Productivity
International	IUSS Working Group WRB, (2015)	Depth/ Stoniness/ Colour/ Texture/ Crack/ Horizons	Certain Mineral (Na, Mn Mg, P)/ Electrical Conductivity/ Cation Exchange Capacity/ OM		
Indigenous	Rushemuka et al., (2014)	Topogrhahy/ Stoniness/ Colour/ Texture/ Depth/ Colour	Parent Material		Fertility
	Bassols and Zinck (2003)	Colour/ Texture/ Consistence/ Soil Moisture (55%)/ Stoniness/ Topography/ Drainage/ Structure/ Depth/ Temperature	OM		Land Use/ Fertility/ Productivity/ Workability/
	Barrios et al. (2006)	Porous/ Depth		Local Plant Variety	Healthy Plant New Soil
	Osbahr et al. (2003)	Consistence/ Colour/ Texture/ Depth			Fertility
	Kamidohzono (2002)	Colour/ Texture/ Topography/ Subsuface			Land Use/ Fertility

Different perceptions

Soil scientists recognize soil as a natural resource, but it is the field of farmers' daily life. Jenny (1941) published *Factors of Soil Formation* and stated that the five factors of soil formation in soil science are 1) parent material, 2) climate, 3) living organisms (especially native vegetation), 4) topography and 5) time (Brady and Weil, 2016). Humans are considered as one of the living organisms within this categorisation. Fry (2001) interviewed Swiss farmers and agronomists about soil and found that they saw soil from different viewpoints. Scientists observe soil as a natural resource based on field surveys and laboratory analysis, but farmers consider soil to be part of their daily experience in the fields. Farmers therefore see soil as one part of their livelihood (Ramisch, 2014).

Different soil depth

The main point of the pedological view is that pedologists recognize soils vertically and observe the soil 'profile'(Ashman and Puri, 2008). Soils are not vertically uniform, but create a layered structure through soil formation from the parent rock. These layers are called soil 'horizons': the characteristics of each horizon are related to the characteristics of soil processes and the environment where the soil layers were formed. Each horizon is given a name, but not all soils have all multiple horizons present at one time; from the top, the O horizon is a zone of OM, A horizon is a zone where mineral and OMs are intimately mixed (often referred to as 'topsoil'), E horizon is a zone where soil is depleted of material, B horizon is a zone of accumulation, C horizon is layer of unconsolidated parent material and R horizon is consolidated parent material (Brady and Weil, 2016) (Figure 2-3). On the other hand, edaphologists and others tend to focus on the top 10-30 cm of soils where plant roots grow.

Local farmers tend to use information only about the surface soil to inform their decisions because it is more visible and considered more important for their crops (Williams and Ortiz-Solorio, 1981; Niemeijer, 1995). However, the special features of soil horizons in subsoil can be included in indigenous soil fertility classifications, as in Sumatra, Indonesia (Kamidohzono et al., 2002).

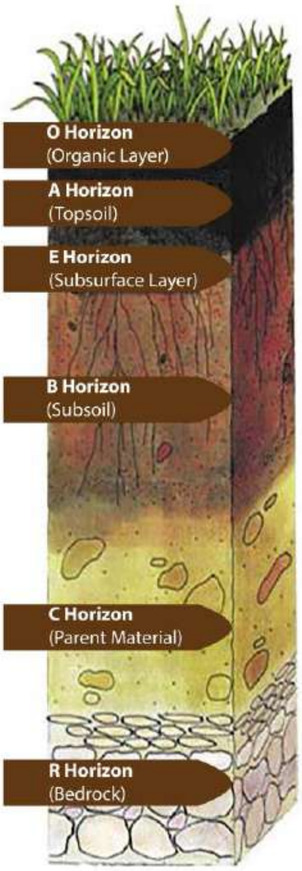

Figure 2-3 Soil profile (cited from https://bhn.us/tag/huma-gro/, SSSA)

Different observation items

In general, farmers have 'know-how' or 'practical knowledge' about soil, and scientists have a deeper scientific knowledge, or 'know-why' about soil (Ingram, 2008). Scientists observe soils from the standpoints of 'reductionism', a concept that explains the "breaking down of a complex phenomenon into simple parts" (Aikenhead and Ogawa 2007: 549), while farmers have a holistic view of their farm.

For quantitative analysis, soil scientists usually take soil samples from fields and analyse them in a laboratory in order to collect detailed data about their physical, chemical and biological properties. These properties are related to soil processes, so from the observation of properties, soil scientists estimate the quality of soil. An example of the relationship between soil properties and processes (Brady and Weil, 2016) is shown in Table 2-4. Scientists often examine just one or two factors in isolation in order to study more specific processes, for example, their impact on crop performance. One scientific definition of soil fertility is "a soil that is fertile enough to provide adequate root depth, nutrients, oxygen, water and a suitable temperature and no toxicity" (Wild, 2003: 51). Soil scientists believe that nutrient status, particularly low levels of P and N in African soils, is a critical factor affecting fertility (Gicheru, 2012). Soil scientists use qualitative measurements for classification and mapping. In particular, the decision to establish border lines for each horizon and colour depends on 'expert judgement'. Tests for texture and moisture in the field also depend on the feeling on researchers' fingers.

Table 2-4 Soil properties and soil processes (Adapted from Brady and Weil (2016))

Soil properties		Related Soil processes		
Physical	Texture	Water retention	Drainage	Aeration
		Cation exchange	Macro-micro fauna/flora activity	
	Colour	OM	Water content	Oxidation
		Drainage status	Particular minerals	Acidity
Chemical	pH	OM decomposition	Cation exchange	Plant growth
		Mineralization	Micro fauna activity	Particular minerals
	Organic matter (OM) content	Mineralization	Water retention	Drainage
		Buffering capacity	Macro-micro fauna/flora activity	Cation exchange
Biological	Macro fauna	OM decomposition	Aeration	Aggregation
	Micro fauna	OM decomposition	Mineralization	Rhizobacteria
		Aggregation	Breakdown of toxic material	Nitrogen fixation

In indigenous soil classification, chemical properties are rarely considered (see Table 2-3). The reason for the difference is that the measurement of chemical properties requires specific chemicals and equipment, so instead farmers rely on assessments of the soil's chemical composition based on an evaluation of crop growth and observation of the soil's physical properties. Indigenous soil knowledge is connected with other environmental information. For example, soil evaluation may be related to climate conditions. Darker soil is seen as a sign of high moisture, and farmers prefer to plant high value crops in those areas because they will benefit from soil moisture in the dry season (Mairura et al., 2007).

Furthermore, indigenous evaluation of their is holistic (Barrera-Bassols and Zinck, 2003); farmers see soil condition resulting from a suite of complex interacting environmental and social factors. In Kenya, when scientists and farmers talked about 'low agricultural productivity' factors, scientists attributed them to soil-based or agronomic reasons such as insufficient nutrient inputs or unsuitable choice of crop varieties but farmers mentioned social and livelihood factors, including small farm size; they also considered climate change (Ramisch, 2014). The farmers felt that lack of a good market discouraged any attempt to improve agricultural productivity (Ramisch, 2014). In the case of France, when farmers and researchers talked about the flow of water, farmers said reducing the speed of flow was important to manage run-off, but scientists talked about the quantity of water flow based on spatial models (STREAM for example) (Mathieu, 2004). Farmers in southwest Niger use the difference of yield in good and bad rain years for their indigenous taxonomy (Osbahr and Allan, 2003). Duvall (2008) observed the classification of physical geographic features by Mali farmers. From a geological perspective, soil is an element that constitutes the 'ground', being a combination of OM, gaseous substances, moisture, gravel and rock. In addition, Duvall (2008) emphasizes the fact that farmers create clearer and more detailed classifications of land cover, which they consider as a combination vegetation and soil types, rather than just as soils, while many ethnopedology studies describe land cover types simply as soil types.

Scientists focus on observation, examining soil under controlled conditions, but farmers are concerned with finding out which actions will enable them to maintain soil under variable conditions. Therefore, even though farmers and scientists use similar qualitative measures to assess soils, they build different conceptual frameworks around this topic. The degree to which farmers understand the relationships between soil indicators or properties and soil processes is still unknown.

Different spatial scales

National soil classification based on soil properties started in Russia in the end of the 19^{th} century (Vilenskii, 1957). Many countries have national soil classification systems, for instance Soil Taxonomy in the US (USDA, 1999). Since some soil types were found in only a few areas and Soil Taxonomy did not cover all soil types, the harmonization of various national classification systems was needed to establish a common language of soils for the world. Therefore, the World Reference Base (WRB) (IUSS Working Group WRB, 2015) was developed (Ashman and Puri, 2008) and the verification of the national soil classification system has been undertaken. In WRB, physical and chemical properties of soils are mainly observed for classification (see Table 2-3). This is because physical and chemical properties provide quantitative data and are more stable than biological data. While the main purpose of soil classification or mapping is planning soil conservation and soil management improvement to lead to better crops and grass growth, original baseline data for the classification of soils have been generated by the soil survey, a process of topographic and geological mapping relating to pedology, with a focus on soil formation (Brady and Weil, 2016). Originally, soil maps were designed to deliver information for managing landscapes and to create a common language of soils, with underlying general principles that explained complexity. Therefore, generalizations are necessary at the landscape and national scale on which local and national government organisations work (Ashman and Puri, 2008): this causes deviations between the scales for farmers' and scientists' knowledge systems.

Before the establishment of national soil classifications, farmers had already distinguished good soils from bad soils (Vilenskii, 1957). Indigenous evaluation focuses on a smaller scale, related to farm, field and within-field plots, reflecting subtle understandings of soil diversity. Many studies have shown that indigenous soil classification is more detailed than international soil classification (Barrera-Bassols and Zinck, 2003; Osbahr and Allan, 2003). It may be argued that farmers are able to evaluate soils in ways that reflects their farm management, while soil scientists are able to use generalized sample data to explain underlying patterns across landscapes and produce local, regional, national and global maps. Of course, detailed indigenous knowledge has the limitation of site specificity (Cook et al., 1998).

However, in previous research, the locations on which farmers focus while evaluating their soil fertility have mainly been discussed in terms of their natural environment; the effect of social environment has not been clearly explored.

Different time scales

The timescale of the pedological viewpoint is that soils form naturally over thousands of years (Yaalon and Berkowicz, 1997; Brady and Weil, 2016), but soil surveys for assessment focus on the immediate or current condition of the soil (often based on one-time sampling) (Landon, 1984).

The timescale of indigenous knowledge depends on purpose. Farmers remember the history of their soils and how indigenous knowledge has been shaped over decades, including the influence of past management or specific events (that led to improved soil or soil erosion, for example) (Scott and Walter, 1993). However, for agricultural management, farmers focus on real-time productivity rather than the improvement for future (Ramisch, 2014). Therefore, it remains unclear what kind of indigenous knowledge about soil has remained within the community.

Different needs

According to Ramisch (2014), scientists designed field experiments to establish essential records and information; on the other hand, the vast majority of farmers only wanted take-home lessons they could use to build on their basic knowledge and common sense. Different needs can generate frustration between farmers and scientists. Some scientists considered farmers to be poor researchers because they recorded little, while the farmers often regarded scientists as poor farmers when they engaged in field experimentation because they did not show day-to-day farming experience and connection to the land. Farmers need to perform practical experiments themselves and they feel no need to keep good records because their experiments are not rehearsals for the future: real-time performance is most important for them. Moreover, farmers were sometimes sceptical about the utility of the new technology employed in experimentation on farms (Ramisch, 2014). The reason was that control plots and some treatment plots performed badly: this is normal for scientific research, but farmers thought the technology was not working. Their different needs can create miscommunication and mistrust between scientists and farmers.

A summary of differences between the two types of knowledge is shown in Table 2-5. The cognition of soil by soil scientists starts from the concept that soil is a natural resource and their interest is focused on why the soil is formed. This is the basis for their classification of soil and consideration of the relationship between crop productivity and soil types (e.g. Yaalon and Berkowicz, 1997; Ploeg and Kirkham, 1999; Brady and Weil, 2016). In contrast, farmers start to think about soil because of their experience of crop production; then they consider how to use the soil for certain crops. After that, they can distinguish between good and bad soils and understand the properties which decide the quality of soils (e.g. Murage et al., 2000, Barrera-Bassols and Zinck, 2003; Barrios et al., 2006). The summarised ideas about these relationships have been drawn in Figure 2-4 as an original figure.

Table 2-5 The differences between views of soil scientists and farmers

Differences	Soil Scientists	Farmers	References
1. Perception of soil	Natural resource	Part of their daily experience	Fry (2001)
2. Soil depth	Surface and Subsoil	Focus on surface	Niemeijer (1995), Brady and Weil (2016)
3. Observation items	Mainly chemical and physical soil properties, know-why	Physical soil properties, holistic including environmental information, know-how	Barrera-Bassols and Zinck, (2003), Ingram (2008)
4. Spatial Scale	National and Global level, Generalized	Site specific	IUSS Working Group WRB (2015), Osbahr and Allan (2003)
5. Time scale	One-time observation	Include history or focus on real time crop performance	Brady and Weil, (2016), Ramisch (2014), Scott and Walter (1993)
6. Needs	Good records	Good results on time/ take-home lessons	Ramisch (2014)

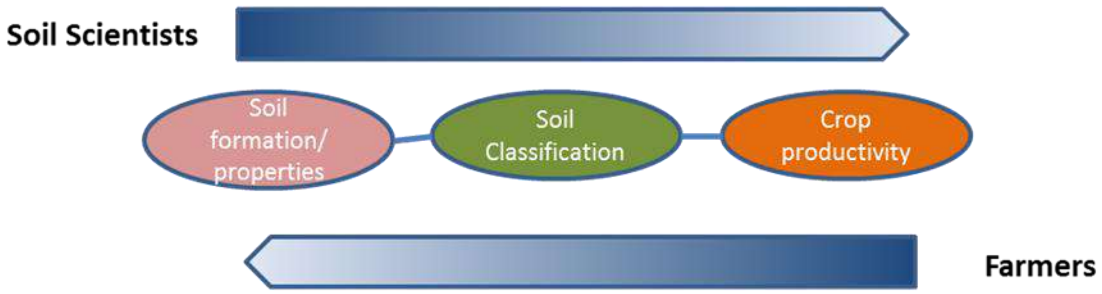

Figure 2-4 Diagram showing the order and intention of knowledge by soil scientists and farmers

As mentioned above, the structures of scientific and indigenous knowledge of soils are different. However, in reality, it is important to recognise that farmers' soil knowledge is not purely 'indigenous'.

Combining Knowledge of Soil Management: present state, difficulty and potential

Farmers try to combine science-based external information and indigenous knowledge in their farming activities to manage risks (Munyua and Stilwell, 2013). The detail of a Kenyan example is shown in 2.5.2 as a decision-making issue. The problems with combining indigenous and scientific knowledge are contextual, and based on farmers' trust or mistrust of indigenous knowledge and the difference between farmers' and scientists' knowledge (see 2.3.3). Mutual understanding between farmers and scientists is not easy, due to the ways that indigenous knowledge systems contrast with scientific knowledge systems (Agrawal, 1995). Some farmers argue strongly against mixing them (Munyua and Stilwell, 2013). These farmers feel uncertain about the outcome of indigenous knowledge, possibly due to the lack of documentation and promotion. Moreover, the scarcity of documentation of knowledge developed within local groups impedes the communication of knowledge beyond specific groups (Marsh and Pannell, 1998). Historically, little attention has been paid to the dissonances between the knowledge of different actors in same development projects, but the dissonances will lead to friction between actors and increase the risk of the project's failure (Ramisch, 2014).

Smith et al. (2015) conclude that sufficient scientific soil knowledge is now available, and that the focus should be on how best to transmit this knowledge for the delivery of sustainable soil management. Within the scientific community, there is a growing realisation of the importance of knowledge sharing, but this two-way process, whereby knowledge is exchanged between the science and farming community, through incorporation of other sources of information, has the potential to create a hybrid knowledge system (Barrios et al., 2006; Prudat et al., 2018). If knowledge exchange is indeed essential (Munyua and Stilwell, 2013; Ramisch, 2014), then two-way communication between farmers and soil scientists is needed to plan suitable soil conservation and land management options (Oldeman, 1992). This approach may help to deliver a more effective and nuanced communication network, where different perceptions are shared between many different actors involved in soil conservation, including farmers, soil scientists, extension officers, governments, the UN and NGOs (Reed et al., 2014). Cronin et al. (2004) and Mercer et al. (2010) mentioned that an integrated strategy between scientific and indigenous knowledge could occur only through a dialogue based on respect and communication between associated stakeholders. In Rwanda, Rushemuka et al. (2014) compared technical and local soil maps to provide a user-friendly communication language, then improved mutual understanding between farmers and specialists and provided effective information for fertilizer distribution by the government.

In summary, some farmers are willing to use only scientific knowledge, while others prefer to combine both scientific and indigenous knowledge to suit their own needs. This raises the next question of how these differences among farmers may arise through approaches to knowledge communication and exchange. The next section introduces the main theories of communication and knowledge exchange that help to explain the construction of hybridised farmers' knowledge, including science and indigenous elements, and these ideas are useful to the research.

2.4. Approaches to knowledge communication and exchange

Scientific and indigenous soil knowledge can be created both inside and outside the community. Knowledge is distributed as external or internal ideas within a community through communication and extension processes. Scientific knowledge usually enters a community as one kind of external knowledge and indigenous knowledge in a community also becomes external knowledge in different communities. Farmers learn new information and create their own knowledge through different learning modes.

These different types of learning can be facilitated by local communication systems and in theory should help the diffusion of new information and technologies across a community. Röling (1988: 33) provides a definition of an Agricultural Information System as "a system in which agricultural information is generated, transformed, transferred, consolidated, received and fed back in such a manner that these processes function synergistically to underpin knowledge utilization by agricultural producers." The definition of an Agricultural Knowledge System is "a system of beliefs, cognitions, models, theories, concepts, and other products of the mind in which the (vicarious) experience of a person or group with respect to agricultural production is accumulated" (Röling, 1988: 33). Farmers' knowledge systems mainly use empirical knowledge and social learning. As a combination of these, the FAO and World Bank (2000: 2) provide the definition of the Agricultural Knowledge and Information System (AKIS): "An Agricultural Knowledge and Information System for Rural Development links people and institutions to promote mutual learning and generate, share and utilize agriculture-related technology, knowledge and information. The system integrates farmers, agricultural educators, researchers and extension workers to harness knowledge and information from various sources for better farming and improved livelihoods".

In AKIS, the first step is communication between various stakeholders. In this research, due to time limitations, the focus is concentrated on communication between farmers and extension officers and among farmers. The key question considered in this section is the process by which both new scientific soil information and indigenous soil information are delivered to farmers. After receiving information through effective communication, how do farmers construct their own knowledge?

2.4.1. Changing approaches from extension to communication and engagement models

Historically, extension is an official communication opportunity whereby farmers can receive scientific and science-based technological knowledge for their field practices.

Agricultural extension involves the conscious use of communication of information to help farmers form sound opinions and make good decisions on their farm practices (Ban and Hawkins, 1988). It is well understood that farmers have historically been the main targets of agricultural management information. The first example of extension was known in Mesopotamia, providing advice to farmers on watering crops and reducing pests (Jones and Garforth, 1997). Until the end of the eighteenth century, experimentation and dissemination of knowledge were focused at the local level and to farmers (Nagel, 1997). After the potato blight crisis in Europe in 1845, the European governments recognized the need to improve farmers' cultivation methods and the modern agricultural extension service came into existence (Jones and Garforth, 1997). From the 1950s, improvements in the agricultural sector have been considered essential for most African countries to support food security and agricultural growth, with this model of extension activity spreading across SSA at around the same time as these countries achieved national independence (Eicher, 2001). However, the extension model has been thoroughly revised and today it is recognised that more than one model of communication approach within agricultural extension is appropriate. The changing trends of extension approaches are discussed below in chronological order.

Linear "top-down" model, transfer of technology (ToT)

Traditionally, ToT was the mainstream for extension (Black, 2000; Ramisch, 2014). The task of extension agencies was to promote the adoption of these 'scientific' technologies by farmers, which generally led to the discrediting of indigenous knowledge. For example, in Australia, extension services were traditionally conducted from Ministry of Agriculture research stations and both on-station experimental research and extension were combined in the same linear approach of science information transfer to farmers. Thus many initiatives were not context-relevant, and farmers did not consider the information applicable to their own agricultural concerns (Nagel, 1997). Furthermore, services failed because the majority of their potential clientele did not receive any benefit, due to economic, socio-psychological and technical limitations: farms were remote and resources were constrained. In addition, farmers' problems were highly diverse and it was difficult for extension workers based in research stations to answer questions about real farms that might have a soil type different from that of the research station, with a different environment and history. The centralization of decision-making and management of the stations reduced the flexibility of extension (Nagel, 1997). As a result, the benefit was distributed to "*only a few favoured farmers in favoured areas rather than the bulk of the farming community*" (Benor and Harrison, 1977: 9).

Training and Visit Extension (T&V)

Due to failures in ToT, T&V was introduced in the 1970s. In this system, the manageable number of farmers per field-level extension worker was improved and the schedule of field visit or training was more frequent. Extension workers were able to provide close supervision with up-to-date information and to concentrate on the teaching of new technology with direct contact with farmers. The contact farmers were chosen as beneficiaries and expected to pass information to fellow farmers with similar problems. However, the implementation of T&V was difficult. Firstly, the flow of information from extension workers to contact farmers, and then contact farmers to other farmers, frequently failed and assumptions about the idea of diffusion have been strenuously debated (Rogers, 2003). In addition, research scientists did not make efforts to interact with farmers and to learn from their experience, because researchers did not have strong incentives for extension. Therefore, the relationship between researchers and farmers was not strong and the mistrust induced a mismatch between demand and extension information (Anderson, 2006). The limited success of T&V induced reforming extension organization is reflected in both large- and small-scale farming.

Participatory Approaches

Through the 1980s and 1990s, a participatory approach gained momentum: in contrast to the ToT and T&V models, it fostered more engaged and meaningful communication. Early development projects that had failed by focusing on individual attitudes and effects had ignored the importance of social, political and economic structures and local agency (Pretty et al., 1995). Participatory methodologies responded by including a ‘bottom-up’ approach, based on the assumption that farmers themselves had the ability to develop sustainable farming systems (Cornwall et al., 1993). The benefits of a participatory approach include drawing upon the accumulated knowledge and experience of the farming community (Cornwall et al., 1993), enhancing local capabilities (Chambers and Pretty, 1993), fitting local problems (Frost, 1998), encouraging producer “ownership” (Marsh and Pannell, 1998) and developing group process (Black, 2000). Participatory methodologies, however, are not without challenges: in particular, they depend on a group focus which can suppress diversity of opinions and even lead to the tyranny of consensus (Carr and Wilkinson, 1997), resulting in a failure to provide specific solutions for some farmers (Metcalfe and Frost, 2000) and high levels of farmer frustration with the complexity of local politics (Black, 2000).

As a recent movement within the participatory approach, Farmer Field School (FFS) was started, initially in Indonesia in 1989 and spreading to SSA. This adult education method focuses on co-learning by a group of farmers. There is an allocated time for engagement with a professional facilitator to help farmers learn by themselves with advice from agricultural extension staffs and engage in experiential discovery learning. FFS has had good results in the reduction of pesticide use, increased productivity, and enhanced knowledge exchange among farmers (Braun and Duveskog, 2009). It also has helped to build human and organization capacity, which sustains long-term interventions. The criticism of FFS is that the approach does not lead to quick or wide extension outcomes (Braun and Duveskog, 2009). Therefore, the effects on economic performance are small and FFS is still seen as having a problem with financial sustainability (Davis, 2006). In addition, achievement is dependent on the quality of resources and facilitators, with flexible improvement in curriculum design and facilitation skill essential (Braun and Duveskog, 2009). The conversion of policy from donor-driven to self-financed and low-cost services with farmers' facilitation is expected as the next stage (Murage et al., 2000; Chuluunbaatar and Yoo, 2015).

Although extension services usually emerge from a centralization approach, decentralization of these services is a strong theme for SSA. The decentralization approach retains the public delivery and public funding characteristics of traditional centralized extension but transfers responsibility for delivery to local governments (Anderson, 2004: 50). This approach was tried by several Latin American governments in the 1980s and 1990s (Wilson, 1991) and in Uganda (Crowder and Anderson, 2002) as well as other African countries such as Benin and Malawi (Davis, 2008). This approach has made it possible to transfer the responsibility for extension to local governments, who are close to farmers and the users of new technology. On the other hand, political interference, a decrease in staff and an increase in costs have stretched capacity. The other decentralized role is the devolution of extension roles to farmers' associations rather than local government. The problem of maintaining agent quality still remains (Anderson, 2004).

Pluralization

Pluralization of extension services has more recently become popular. This refers not only to public services but also to the private sector, especially NGOs, which play a significant role where government resources are constrained. In a pluralistic extension system, collaboration within each sector is vital to avoid duplication of activities and maximize the profits of services (Muyanga and Jayne, 2006). This applies not only to face-to-face extension services, but also the mass media, which also occupy an important role in the distribution of new information. Community media in particular can increase the opportunity for collaboration and networking. Local radio is popular because the device is cheap, relatively easy to use, and requires minimal production facilities (Lwoga, 2010). In addition, farmers consider the radio broadcasts more accessible, reliable and informative than other extension channels (Adolwa et al., 2012). TV and radio drama programmes can be used in Entertainment Education (E-E, Edutainment), which appeals to the audience's emotions through connections to actors (Singhal and Rogers, 2004). Commercial companies involved in extension services promoted new technologies through free trial samples, advertisements and meetings. Local markets also provide a space for farmers to share information.

The original purpose of modern extension was to educate farmers in the use of new technology; it was based on a belief that increased production would automatically follow the adoption of science-based innovations (Black, 2000). Related to that, the definition of extension in its early stage was "a service or system which assists farming people, through educational procedures, in improving farming methods and techniques, increasing production efficiency and income, bettering their levels of living, and lifting social and educational standards" (Maunder, 1971: 3). After the failure of linear extension, the definition was changed to "the conscious use of communication of information to help people form their own opinions" (Ban and Hawkins, 1988: 27). It means that the focus of extension services has changed from extension officers to farmers. Although the words 'help people' are included in each definition as a main point, the activities of extension remain affected by political interference. Röling (1988: 49) defined extension as "a professional communication intervention deployed by an institution to induce change in a voluntary behaviour with a presumed public or collective utility", which illustrates the difference between extension delivery and other communication interventions, such as commercial advertisements or political messaging.

In the 2000s, now that the importance of social learning and negotiation in the extension process has been emphasized by the failure of linear extension, two-way or multiple ways of communication have been developed. Criticism of the limited effectiveness of implementing top-down technology and scientific transfer of information through extension services has directed increasing attention to the value and integration of indigenous knowledge by farmers (Barrios and Trejo, 2003; Berazneva et al., 2018; Guzman et al., 2018; Richelle et al., 2018). Integrating indigenous knowledge helps to match extension workers' efforts with local needs, and may achieve improved adoption of co-produced technology (Ingram et al., 2018). Therefore, the term 'extension', which originally allowed only one-way communication, did not meet its needs and 'communication for innovation' is now commonly used as the approach. Definitions of communication see this now as a process of convergence between ideas, as two or more individuals exchange information in order to move toward each other in the meanings that they give to certain events (Rogers, 2003). However, this has changed in the academic discourse, where the term 'extension' has been used in a more general way (Leeuwis, 2004). Rocheleau (1988 cited in Walker et al., 1995) points 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" (Walker et al. 1995: 236).

Given this history in the development of extension approaches, it remains important to recognise that there are specific interpretations and applications in particular contexts. Each country has its own policy for agricultural extension: therefore, the next section reviews the agricultural extension landscape in Kenya.

Agricultural extension in Kenya

Extension services in Kenya are conducted by a pluralistic system, including the public sector through government and commodity-based extension, and also the private sector, such as seed providers, and NGOs (Muyanga and Jayne, 2006; Davis, 2008). The public extension system remains centralized and the Ministry of Agriculture provides approximately 70% of its budget for extension and research (Muyanga and Jayne, 2006). During the data collection in 2016, the conversion of the decentralized extension system started with the introduction of the County System (See Chapter 3).

The National Agriculture and Livestock Extension Programme (NALEP) is the main government extension programme conducted by the Ministry of Agriculture. It is based on the Strategy to Revitalize Agriculture (SRA) (Republic of Kenya, 2004). The programme targets agricultural and livestock development and poverty alleviation by pluralistic and demand-driven extension services (Republic of Kenya, 2005). It includes the shifting focal area approach in which skilled officers and extension workers work together with farmers for a year before shifting to a new location. NALEP has two types: NALEP-Gok with support from Kenyan government and NALEP-Sida from the Swedish International Development Agency. The group-based approaches are conducted in focal areas by NALEP-Sida at first, and after that, the activities are continued under the supervision of NALEP-Gok. The NALEP phase Ⅰ (July 2000-June 2005) review shows two results: one is that NALEP gives a disproportionate amount of benefits to farmers who have sources of income outside their farms and high knowledge status; the other is that poor farmers dislike taking risks and using new technology (Republic of Kenya, 2006).

The Kenyan Agricultural Research Institute (KARI, currently the Kenya Agricultural and Livestock Research Organization, KARLO) embarked on its Agricultural Technology and Information Response Initiative (ATIRI) to establish the new technology in rural areas. It included activities like pioneer farmer visits by other farmers and field visits by members of the institute's staff (Gustafson, 2004). In Kenya alone, there are over 1,000 FFS with 30,000 farmer graduates (FAO/KARI/IRLI, 2003). However, the access to extension information remains unequal, being particularly poor in remote areas. The problem of decreasing communication with extension officers is getting worse due to a decrease in the number of officers after the introduction of the County system (personal communication with an agricultural extension officer in Kitui County, Kenya).

Consequently, despite the development of extension services and information technology, the inequality of extension services has resulted in the unequal distribution of agricultural information, including soil information. The main causes are location and gender.

Location: Small scale farmers who live in remote areas may find it difficult to engage with extension services because of high levels of illiteracy, limited access to mass media or high transport costs (Anderson, 2006). The cost of transportation is a challenge for extension services because, even if farmers have questions, they may not be able to visit extension workers, who are centrally located. According to Muyanga and Jayne (2006), the distance from extension services varies across Kenya but overall the long distance to extension support is an important factor that helps to explain low maize productivity in some areas. They suggest that either the distance to extension services affects the production of maize or that extension services are reduced because the area has low production. Even though the pluralistic extension system is common in Kenya, both government and commercial extension services usually tend to focus on non-poor farmers in appropriate areas, while poor and small scale farmers in isolated areas are neglected (Muyanga and Jayne 2006).

Gender: The design of development policies and projects may implicitly focus on support for men as culturally they are perceived to be the main target, even though women shoulder many of the burdens of agricultural production and are responsible for household food security (Cornwall, 2003; World Bank, 2008).It is difficult for female farmers to access markets, other key productive assets and services: land, labour, financial services, water, rural infrastructure, technology, and other inputs (Kabeer, 2005; World Bank FAO and IFAD, 2008). In Ethiopia, there are significant differences in the rate of primary education, attendance in community meetings, and access to information: the fact that extension officers visit farm heads (usually men) has made it difficult for women to access information from extension services (Ragasa et al., 2013). A similar situation in Kenya was also reported and gender-based inequality still persists, so Kenya was selected as a participating country in USAID's Women and Girls Lead Global Partnership for addressing gender equality (USAID Kenya, 2018).

Not only the opportunity to access and benefit from extension, but the uptake of new soil management information is also different among farmers and is shaped by livelihood dynamics, including livestock value, off-farm income and education level (Adolwa et al., 2012). Livestock value and off-farm income can be seen as indicators of wealth status and are related to the capacity to try new methods, and a higher education level is needed to effectively understand knowledge-intensive technologies. Related to that, farm profitability is related to agricultural qualifications acquired by farmers' participation in training events (Bamberry et al., 1997). Kilpatrick (1996) found that participating farmers are more likely than others to make changes in their field practice. Moreover, Africa traditionally has 'oral (unwritten) literature' (Finnegan, 2012). Direct communication is the main way to transfer information and it is different from contemporary Europe's written literature, which can be distributed by written copies (Finnegan, 2012).

In summary, extension services have evolved to recognise the needs of different farmers, and provide more behaviour and education-oriented communication activities, but the problem of limited diffusion and uptake of information remains. As discussed, many factors prevent effective distribution of information from extension officers and between farmers, especially to isolated, poor or female farmers. However, the effects of inequality of access to information for the implementation of their soil management and the combination of indigenous and scientific knowledge have been rarely mentioned in the previous research.

2.4.2. Farmers' learning and cognition modes

This section considers the different learning and cognition modes: how, where and with whom farmers construct their own knowledge, and how they recognize the conditions and problems in their fields.

What learning is and how to learn are still difficult to define (Muro and Jeffrey, 2008). Learning is a multifaceted phenomenon. Marton and Säljö (1979; cited in Muro and Jeffrey 2008) stated that it includes (1) acquiring information and increasing knowledge; (2) memorizing; (3) acquiring facts, skills and methods; (4) making sense or abstracting meaning; and (5) interpreting and understanding reality in a different way by reinterpreting knowledge.

There are three modes of learning: self-directed, collaborative and institutional (Smith, 1983). Self-directed learning is individual learning and includes 'experimental learning'. Experimental learning is continuous interaction and iteration between thinking and action: concrete actions result in certain experiences, which are reflected upon and generate cognitive changes, from which new actions can emerge (Kolb, 1984; Leeuwis et al., 2004). It is the central process of human adaption to the social and physical environment rather than an educational concept (Kolb, 1984). Collaborative learning is done by two or more persons: collaboration with others is one of main elements of 'social learning'. The idea of social learning was formulated first by Miller and Dollard (1945). The idea was based on other learning theories and started from the study of imitation. In social learning systems, new behaviours can be acquired through direct experience or by observing the behaviours of others with whom one must interact (Bandura and McClelland, 1977). Finally, institutional learning occurs as formalized instruction, as in school. The learning provision from extension services is often included in this mode. Each person will have their own 'learning style' that represents "the individual's characteristic way of processing information, feeling and behaving in and towards learning situations" (Smith, 1983: 60). For example, some people like to understand the big picture first but others want to know specific examples and details first. Another example is when some people want to learn the theory first while others prefer to focus on practice first. Farmers learn about soil from their childhood through their families' upbringing and social context, and even after becoming adults. The characteristics of adult learning are explained below.

Learning by adults includes specific features distinct from children's learning processes (Smith, 1983). First, adults have different orientations towards learning, since they have multiple roles, responsibilities and opportunities for learning. Secondly, they have various personal experiences and learning is preceded by re-integrating the meanings, values, strategies and skills from their experiences. Thirdly, there are specific periods for developing their learning. In each life stage, people have certain needs and roles to learn, and not only personal issues, but environmental and social change also affects motivation for learning. Finally, adults may have greater awareness of anxiety and uncertainty about learning than children, especially if they doubt their personal learning ability (Smith, 1983).

Cognition is an important step in learning, and cognitive factors affect learning style (Smith, 1983). Scientists and farmers differ with respect to these factors. The first difference concerns field-independence and field-dependence. Field-independent people tend to perceive elements independently from environment and background. They are able to see elements from different perspectives and in an analytical way. By contrast, field-dependent people tend to treat a total field as a whole and see elements in the relationships with environment and background. This focuses on conceptualizing and categorizing. Conceptualizing is finding similarities based on the external, objective, physical attributes of information. In categorizing, the self does not play the central role and uses external categories for cognition of relationships. Some people have a tendency to reflect more than others and some may prefer impulsive thinking. Finally, there are three major sensory modalities, relating to people who prefer thinking to be based on the physical, on visual information or on verbal expression. Tsur et al. (1990) argued that it is not unusual for risk aversion to positively affect learning since some people will not want to take a risk and will not seek to learn new information leading to long-term effects.

Social Networks for learning

Social networks perform two roles within a local community: as a web of information and a place for social learning. Jackson and Quaddus (2006) emphasized the importance of information networks for innovation. Extension must understand the structure of a community's information network to be effective. Farmers are likely to exchange information only with relatives (Ramisch, 2014) and others of their own class (Longo, 1990), and farmers' group members rarely share their knowledge with non-group members (Munyua and Stilwell, 2013). Moreover, some farmers do not want to share their knowledge because of fear of criticism, idealism or isolationism (Ingram, 2010). Richer farmers, and those who farm larger extents of land, may find it easier to adopt new technology than others, so those farmers frequently become beneficiaries of extension services (Feder and Slade, 1984), and innovative farmers are connected by information networks to researchers and agronomists (Ingram, 2010). Therefore, larger farmers are expected to be mediators between the external world and their community.

There have been many studies that show elite capture of information and resources in Africa (e.g. Kiplang'at 1999 in Kenya; Opara 2008 in Nigeria; Lwoga 2010 in Tanzania). However, these studies of information flow are mainly about external knowledge. There have still been few studies of the distribution of indigenous knowledge that include the integrated relationship among information, livelihood strategies and actual management in the fields.

As for the role of a social learning space, considering the dissonance among farmers and between farmers and soil scientists/extension officers can have positive effects, like defining their problems with more accuracy and improving the quality of the decisions by using a combination of knowledges. There are also negative impacts from collaboration, including conflicts among different ideas (Muro and Jeffrey, 2008). Therefore, Paassen (2004) stated the importance of improved problem-solving capacity and the role of organizational and extension skill building in government extension services.

In summary, top-down extension services have changed, to adopt more communication and participation with farmers. However, the inequality of access to extension officers has continued among farmers and affected their learning opportunities. Farmers also find social networks in their community and empirical learning is important for knowledge exchange and construction. Then, after knowledge exchange, how do farmers decide to implement their new knowledge?

2.5. Implementation of knowledge for sustainable soil management

Through communication and various learning opportunities, Farmers construct their own knowledge, but they must make the decision whether or not to use it in practice. For example, it is well known that fertilization can increase crop yield, and land management practices such as tied ridging and terracing can enhance crop production by reducing the damage from soil erosion (Kiome and Stocking, 1995). Both knowledge systems and the "process of adoption" (Prager and Posthumus, 2010) contain the same concepts, because knowledge construction is important for adoption and vice versa. Nevertheless, both personal and external factors, including learning opportunity, prevent or accelerate different farmers' implementation of their knowledge of these soil management practices (Ajzen, 2002). The factors affecting decision-making also affect individual adaptation capacity. To explore this, it is necessary to understand theories about decision-making. How do farmers value their new knowledge and why do they decide to implement it in their fields?

2.5.1. Decision-making and limiting factors

Decision-making as an academic term

The definition of decision-making is "*the action or process of making important decisions*" (Trumble and Stevenson, 2007). Studies in the past considered decision-making as an event, not a process (Klein and Orasanu, 1993 cited in Öhlmér et al., 1998). Theories of management considered this process as based on the expected utility hypothesis[1] and neglected optimization with problem definition, learning and decision-making rules (Öhlmér et al., 1998). Moreover, there was a strong trend to consider decision-making as a series of linear steps.

The process of decision-making is more complex than expected, involving grouping and a cyclical process (Mintzberg et al., 1976). There is no one-size-fits-all process for making every decision and some steps may be eliminated, depending on time factors and other aspects of the situation. Theories explaining the individual internal aspects of decision-making can help to conceptualise the reasons why different people may decide on different approaches.

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[1] expected utility hypothesis: individuals choose in such circumstances as if they were seeking to maximize the expected value of some quantity (Friedman and Savage 1952: 463)

Theories about decision-making

Social Cognitive Theory (SCT): SCT was introduced by Bandura (1986) as a new model derived from his social learning theory. SCT has a concept of 'triadic reciprocality', whose three components, environment, person (cognition) and behaviour, make recursive determinations (Muro and Jeffrey, 2008). In SCT, the effect of cognition on behaviour was emphasized and Bandura (2001: 4) stated that "The human mind is generative, creative, proactive, and reflective, not just reactive." There are two types of expectation in SCT. Self-efficacy is "the conviction that one can successfully execute the behaviour required to produce the outcomes" and outcome expectancy is defined as "a person's estimate that a given behaviour will lead to certain outcomes" (Bandura 1977: 193). However, SCT, like 'learning', has aroused objections, on the grounds that not all behaviour changes are induced by cognition, and cognition cannot make new behaviour on its own (Muro and Jeffrey, 2008).

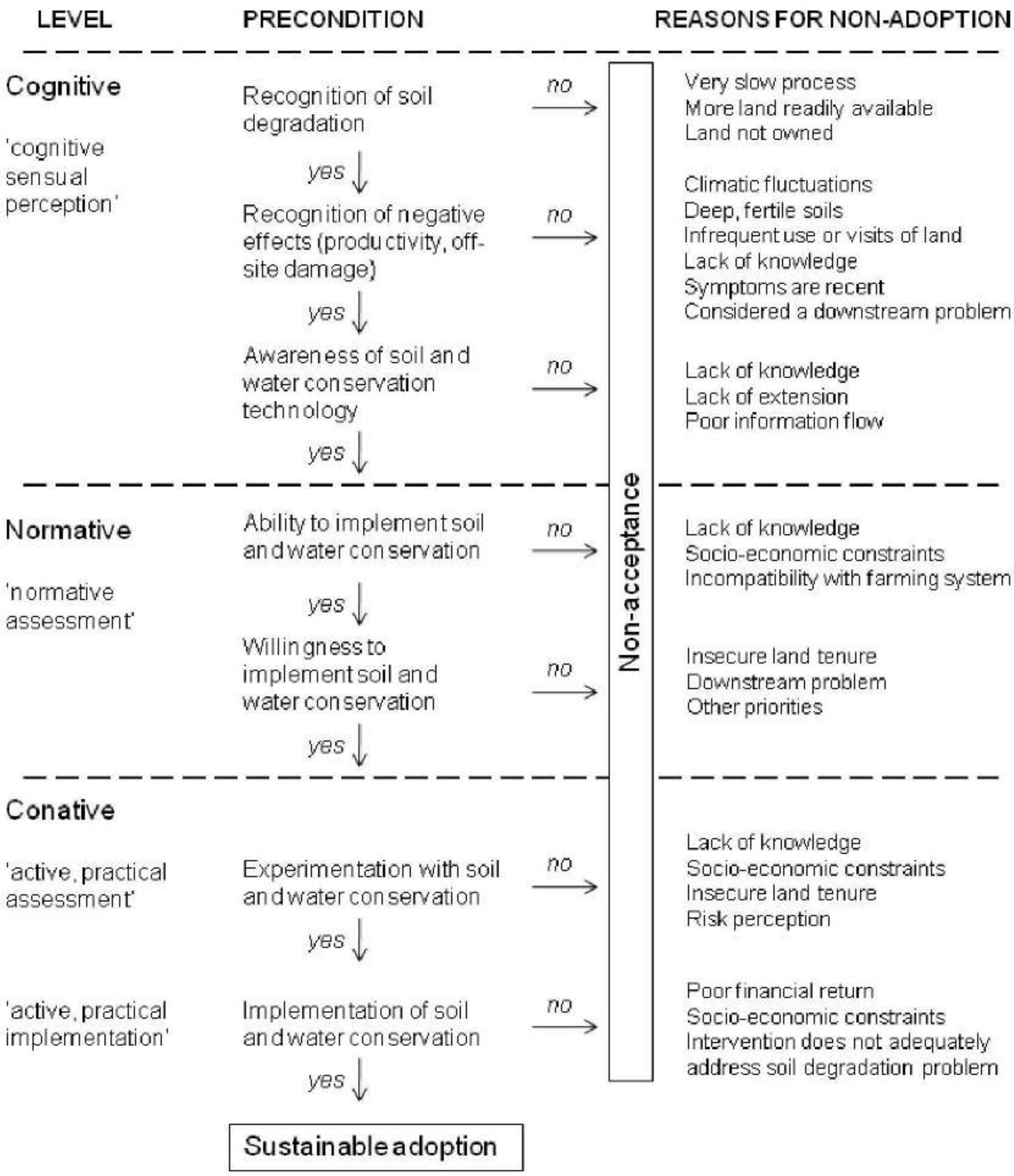
Theory of Reasoned Action (TRA) and Theory of Planned Behaviour (TPB): TRA states the main factors of behaviour are 'intention' to perform the behaviour, and how hard people are willing to try (Ajzen, 1991). The creation of intention is controlled by other factors, such as availability of opportunities and resources, so TPB was developed based on TRA. TPB includes three conceptually independent determinants of intention. First, 'personal attitude towards behaviour' is a person's evaluation of the proposed behaviour (favourable or non-favourable to action). Secondly, 'subjective norms' are social factors which apply pressure to act or not to act. Lastly, 'perceived behavioural control' is confidence in a person's capacity, which reflects past experiences (Ajzen, 1991; Paassen, 2004).

The first criticism of TPB concerns the definition of the attitude at the first stage. In behavioural theory, belief is separated from attitude but related to emotions connected with the behaviour. Therefore, in recent years, belief has been considered in TPB studies (Paassen, 2004). Although Beedell and Rehman (1999) showed the effect of perceived behavioural control on farmers' decision-making is smaller than that of the other two, the study sample are British farmers so the situation would be different from that of African farmers. In addition, Armitage and Conner (2001) represented direct and indirect effects of perceived behavioural control by meta-analytic review of 161 studies. Recognising these dimensions is important to any study of soil management: this research adopts these three determinants of intention as a conceptual lens to organise and explain differential decision-making in the case study. Taking this approach means the research moves beyond traditional approaches to soil management that focus on the resources available to farmers (Karanja et al., 2017). Few studies have actually contextualised the variation of these perceptions as a reflection of individual resources, perceived attitude, subjective norms and perceived behavioural controls, but doing so can provide a deeper understanding of patterns of investment in adaptive crop and soil management (Rao et al., 2011; Karanja et al., 2017).

Factors of Decision-making and Adoption

A decision is "*neither completely rational, completely irrational, nor completely non-rational*" (Guitouni and Martel 1998: 504). When individuals and communities decide something, perception of risk, knowledge, and experience are assumed to be important factors (Adger et al., 2009). Factors controlling decision-making are not only internal (such as skills, knowledge, background, willpower), but also external (such as location, degree of difficulty of problems, availability of assistance, time, and money) (Ajzen, 2002). In addition, ethics and culture could become factors for adaptation, but the effect is mutable (Adger et al., 2009).

'Adoption' is a term related to decision-making and the meanings overlap: Choosing to take up, follow, or use something (Trumble and Stevenson, 2007). Decision-making includes the process and adoption is the decision to use something. The factors for adoption are categorized as follows: 1) access to natural resources, capital and information, 2) learning and investment costs, 3) Risk attitude, 4) (Perceived) severity or urgency of problem, 5) Personal factors including human values, experience and education (Posthumus et al., 2010; Prager and Posthumus, 2010). Prager and Posthumus, (2010) clearly show the process of adoption with various related factors as a figure (Figure 2-5). The question that this study is interested in is what might then lead to these different decisions – why do some farmers innovate or invest in their soil management practices?



Source: based on Ellis-Jones and Mason, 1999; Prager, 2002; Esser, 1999; Graaff, 1996; Lionberger, 1960.

Note: The arrows do not imply that one precondition necessarily follows the previous one. Rather, the individual needs to "pass" the group of preconditions at each level and finish positively in order to proceed. In real life, there may be loops, short-cuts, back stepping or interruptions of the process.

Figure 2-5 Levels and precondition of the adaption process (Prager and Posthumus, 2010)

A Kenyan Example of Farmers' Decisions Made by Combining Scientific and Indigenous Knowledge

In Kenya, farmers merge indigenous and scientific of knowledge for pest and disease control, soil fertility management, and crop selection. Farmers use different types of knowledge in a series of steps.

They start with indigenous methods, but if there is a problem they will then try external technology, including pesticide (Munyua and Stilwell, 2013). They follow this process because Western knowledge can be applied in the local situation (Turnbull, 1997), but some farmers lack the funds for new technologies. One farmer remarked, *"External (scientific) knowledge is more profitable but local (indigenous) knowledge is more sustainable"* (Munyua and Stilwell, 2013). However, the majority of farmers use science-based agricultural knowledge in their agricultural practices. The farmers preferred scientific knowledge to indigenous knowledge because it was considered more reliable, accurate, and relevant to farmers' need (Munyua and Stilwell, 2013) as well as essential for improving livelihoods (Pretty, 2003). This demonstrates the contextual basis upon which farmers' trust in scientific knowledge became the intention for their decision making but Why they trust it was not clear from the literature.

2.5.2. Moving from coping to Innovation, adaptation and enhanced adaptation capacity

The pressure of climate change is one factor that has driven the adoption of successive coping strategies to develop into the diffusion of innovations enabling people to adapt to the current situation. Innovation is an idea, practice, or objective that is perceived as new by an individual or other unit of adaptation (Rogers, 2003). According to Diffusion of Innovation Theory (Rogers, 2003), diffusion is the process in which an innovation is communicated through specific channels over time among members of a social system.

The term 'adaptation' originated in the field of evolutionary biology, meaning a process, action or outcome in a system to better manage or adjust to a change or difficulty (Smit and Wandel, 2006). The process leading to adaptation is not directly and quickly experienced by every person or in every situation. When farmers face a crisis or difficulties, they may first 'cope' with their situation. Coping is considered a short term action, but the continuum of coping may become 'adaptation' if there are incremental changes and longer-term change (Smit and Wandel, 2006). Individuals will vary in their ability to cope with or adapt to crisis (Adams et al., 1998); therefore, it is possible to consider a 'response space' for individual impact recognition, coping and adaptation (Osbahr et al., 2010). There are only a small number of innovators (2.5%) or even early adapters (13.5%) that adapt to a new idea; then the early majority (34%) and late majority (34%) follow, with laggards (16%) remaining (Rogers, 2003). As well as a difference in response time, there is a difference in the quality of response. If some choices for coping with the new situation create negative externalities, they are not sustainable and can increase vulnerability in the long term. These actions are called "maladaptation" (Jones et al., 2010).

The determinant of the quickness and quality of adaptation processes and action is individual farmers' ‘adaptation capacity’. Smit and Wandel (2006) sorted the factors which influence adaptation capacity at local level: managerial ability, access to financial, technological and information resources, infrastructure, the institutional environment within which adaptations occur, political influence, kinship networks etc. In addition, ethics and culture are factors for adaptation but their effect is mutable (Adger et al., 2009). The examples of the effects of these factors is shown in Table 2-6 as an original idea. When Table 2-6 is compared with Figure 2-5, it appears that the factors affecting the adoption process also affect adaptation capacity. It appears that the adoption of new or hybrid knowledge for solving various problems is needed to adapt to current agricultural difficulties. The Intergovernmental Panel on Climate Change (IPCC, 2001) argued that agriculture in Africa must adapt to inter-annual climate variability in order to cope with longer term climate changes. To avoid maladaptation by farmers who have small adaptation capacity, the development of adaptation capacity is essential (Jones et al., 2010).

In AKIS (see 2.4.2) the focus is on knowledge and information about farm practice, and the Agricultural Innovation System (AIS) includes the role of the market and government policy to strengthen farmers’ capacity to make innovations in the range of their agricultural production (Hall et al., 2006). The AIS actors also come from a wider professional range than AKIS: they include farmers, processors, traders, researchers, extension workers, government officials, and representatives from input industries and civil society organizations (Klerkx et al., 2010). Four Directions Council (1996: 5) states that, where indigenous (traditional) knowledge is concerned, “the social process of learning and sharing knowledge, which is unique to each indigenous culture, lies at the very heart of its ‘traditionality’”. Not only do communities differ, but each farmer will place a different value on new learning and different styles of communication, responding with different degrees of trust and motivation. These differences will reflect personal attitudes, subjective norms and perceived behavioural controls. Knowledge is constructed from a mixture of both local and external sources of information, and while different types of farmers prefer different sources, most develop a hybrid understanding (Munyua and Stilwell, 2013). Although this thesis has not covered the roles of policy and markets, its findings will make a valuable contribution to the adaptation of policy to local needs.

This thesis seeks to provide further explanations for why farmers who live in areas unfavourable for farming (due to climate and/or soils) may sometimes be risk-averse; farmers may not perceive themselves to have the capacity or knowledge to respond within their agricultural system and instead take limited action or facilitate alternative livelihood strategies to cope, such as non-farm activities (Tanaka and Munro, 2014).

Table 2-6 Factors for adaptation capacity and examples of their influence on farmers (adapted the factors from Adger et al., 2009)

Factors for adaptation capacity	Example of influence	
	Positive	Negative
Managerial ability	Farmers who can think by themselves, combine new and old information.	Farmers who just follow others, don't know how to use new information.
Access to financial, technological and information resources	Farmers who can access these resources, increase the frequency and amount of new information and support.	Farmers who cannot access these resources, have less opportunity to gain new information and support.
Infrastructure	Farmers who live in communities with good infrastructure y, have the basis of new technology.	Farmers who live in isolated area, need more initial investment.
Institutional environment	Farmers who live near extension offices, able to get support from others.	Farmers who live far from extension offices, have less support from others.
Political influences	Farmers who are selected for extension and/or subsidy programmes, support from government.	Farmers who are rejected from extension and/or subsidy programmes, have less support from government.
Kinship networks	Farmers whose families are rich and/or knowledgeable, have support and information from family members.	Farmers whose family is poor and/or lack knowledge, have less support from family.

Revealing the determinants of farmers' intentions moves the research beyond traditional approaches in soil management that focus on the resources available to farmers. Instead, it facilitates understanding of how different farmers' perceptions of environmental risk, including climate change, shape on-farm soil management decisions. Yet TPB suggests that farmers would need to perceive a reason to change as well as have the resources to do so: research has demonstrated that farmers' perceptions of climate trends do not always match meteorological observations (Ovuka and Lindqvist, 2000; West et al., 2008). However, few studies have actually contextualised the variation of perception as a reflection of individual resources, perceived attitudes, subjective norms and perceived behavioural controls, but doing so can provide a deeper understanding of patterns of investment in adaptive crop and soil management (Rao et al., 2011; Karanja et al., 2017). Technologies help to reduce risk and uncertainty, but adoption and experimentation with technology have been shown to reflect individual experience of on-farm trials, mechanisms for sharing learning, personal attitudes to taking risks and the ability to do so effectively (Ghadim et al., 2005).

In summary, both adaptation capacity and intentions are important for innovation. However, adaptation capacity and intentions will continue to differ among farmers and the effect on their management should be studied. The farmers who participate in these studies are described only by general information (e.g.

schooling, age, gender), or just called ‘farmers’, and the data were taken from the group as a whole. Each farmer must have a different combination of livelihoods and intentions, and these factors must affect farmers’ decision-making.

2.6. Conceptual framework and research gaps

Based on the literature review, a conceptual framework of this study has been constructed and research gaps summarised to clarify this study’s contribution to the current debates.

2.6.1. Conceptual framework

This section brings together the ideas described above to develop a conceptual framework for this research and to support the development of the research approach. The circulation of knowledge construction is reviewed in the context of research on indigenous knowledge systems (Röling, 1988) and the process of adoption (Prager and Posthumus, 2010).

These ideas are conceptualised in Figure 2-6 to show the steps and interactions which help to shape the research design. The overlaps and connections in the theories are outlined in sections 2.3, 2.4 and 2.5. Due to the time limitation, this study targeted three concepts from this flamework.

1. The first target is the comparison of scientific and indigenous knowledges about soil; the importance of understanding these different knowledges and how they interact each other. This relates to the first step in the diagram. The enhancement of mutual understanding of scientists and farmers is connected to the creation of hybrid knowledge (Barrios et al., 2006), mentioned in 2.3.3.

2. The second builds on the interaction of concepts about soil fertility within farmers’ thought processes; how soil fertility is understood conceptually and how this understanding differs among farmers. It is related to the holism of indigenous knowledge (see 2.3.3) and the knowledge gap among farmers, which is one of the research gaps among current debates. The creation of one’s own knowledge is mentioned in the middle of the diagram.

3. The last is the linkage of communication, decision-making and adaptation; when new knowledge of soil management method enters the system, it is passed to farmers through communication with extension officers, neighbours or family members. Mass media provide

further communication channels. When communication takes place, the farmers learn and own the knowledge as theirs. If they believe that trying it will be of value, they decide to implement the knowledge in their fields. The likely effect on soil fertility also affects their decision. Next, if the results of the implementation are good, farmers decide to adopt the new method. Then a new innovation is integrated into indigenous knowledge, so this knowledge system continues to circulate. Communication with extension officers (see 2.4.1), the process of adoption (see 2.5.1) and TPB (see 2.5.1) are the main theories surrounding each step. Communication, decision-making and adaptation are the relevant concepts in the diagram. In addition to the process, there are external and internal (personal) factors creating inequality among farmers in communication, learning, decision-making and adaptation. The factors affected for communication and decision-making are also studied in this thesis.

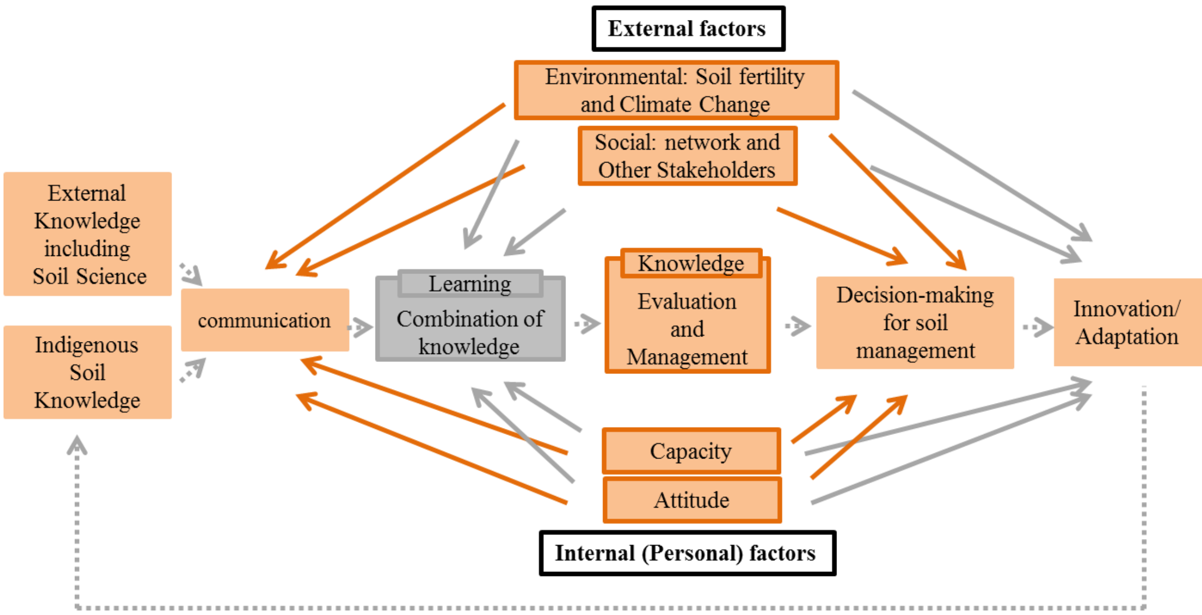


Figure 2-6 Conceptual framework

2.6.2. Research gaps

The research gaps in each of the three key concepts are summarized below.

Knowledge systems

As mentioned in 0, the effects of time scales, spatial scales, differences among farmers and the relationships between soil properties and processes on indigenous soil evaluation are still unclear. The variation of indigenous knowledge between members of the same community is another research gap that requires to study. The effect of environmental and social changes on the construction of local soil knowledge has not been mentioned in many ethnopedological papers (Kamidohzono et al., 2002; Barrera-Bassols and Zinck, 2003; Rushemuka et al., 2014). Farmers' evaluation of fertile and unfertile soils needs to be observed, with particular reference to the detailed location information. Although the correlation between indigenous soil evaluation and scientific analysis is clear (Kamidohzono et al., 2002; Mairura et al., 2007), farmers seem to perceive soil nutrient status indirectly, from crop productivity (see Table 2-3). The scale and location of fertile and unfertile soils are observed through field visits. Soil samples are also taken to evaluate the nutrient status of the soils. Data on the influence of historical events on soil knowledge were collected thorough group discussions and individual interviews with farmers (see 3.5.3).

It is still unknown whether or what kinds of soil properties and processes farmers recognize. The concept of 'fertility' appears to be have different meanings for scientists on one hand, and farmers on the other (Ingram et al., 2010; Ramisch, 2014), but it is assumed that there are also differences among individual farmers. The creation of mental models (Prager and Curfs, 2016, see 3.5.6) has the benefit of visualizing knowledge systems. However, this approach has rarely been applied to soil science in Kenya and to assessing similarities and differences among farmer knowledge. The use of mental models for visualizing indigenous and scientific knowledge systems concerning soil fertility, particularly in the context of a developing country, would help to extend understanding of the structure and the content of farmers' knowledge (see Chapter 5 and 6).

Communication and knowledge exchange

A gap in the studies on the combination of external and indigenous knowledge is farmers' assessment of its value, and consequently their ability to select or combine knowledge (see 2.3.3). Is it related to the resulting yield or trust in the information's origin? What are the sources of their information: extension officers, teachers, neighbours or family members? The evaluation methodology applied to farmers' acquisition of knowledge also requires greater attention from soil scientists, because this influences how effectively soil-related knowledge can be shared with soil managers (Smith et al., 2015). The effect of inequality of information among farmers also needs to be observed (see 2.4.1). These data relating to communication have been taken in individual interviews with structured questionnaires (see 3.5.4).

Decision-making

The analysis of a flow from communication to farmers' decision-making based on soil knowledge (e.g. for crop choice, seeding or fertilization) is rarely derived from previous studies. The effects of farmers' differing perceptions of risk and their intentions on their soil management must also be observed in the context of current climate change. When considering the factors affecting farmers' decision-making strategies (see 2.5.1), the quantitative categorization of farmers is not enough to shape the contexts of their knowledge system: variations between farmers' intentions should be taken into account.

2.7. Summary

Sustainable soil management is fundamentally important to the livelihoods of communities across the world. It is a particular issue in SSA including Kenya, where there are problems of low soil fertility and climate change. Although various attempts have been made to provide agricultural extension, as internal policy and through international programmes, they have been hampered by the inequality of extension between and among communities, and the situation is becoming worse because of the current reduction in the number of extension officers.

Indigenous soil knowledge should not be considered as exclusively conservative and incapable of accommodating outside influences. It is constructed holistically by daily experience and observation, combined with both familiar ideas and information from external sources. Since farmers have used it while making decisions about soil management, there is a space for further study of the relationship between indigenous soil knowledge and soil science, local history and location. Indigenous knowledge systems include multiple factors applicable to the adaptation of new technology and the generation of hybrid knowledge. Further investigation is necessary to reveal more fully the complexities of this system.

Therefore, the key conclusions and research needs identified from the literature review are: 1) to understand the relationship between farmers' and scientific knowledge of soil fertility, particularly common indicators, and how farmers understand soil fertility in terms of their location and history (reflecting on Objective 1 and Chapter 4); 2) to understand the deeper structure of indigenous knowledge systems concerning soil fertility, especially soil properties and processes, by using mental models (reflecting on Objective 2 and Chapter 5 and 6); and 3) to understand the flow of knowledge systems through information sources, learning and decisions made about field management and adaptation to risk from climate extremes (drought and floods), with a focus on farmers' narratives (reflecting on Objective 3 and Chapter 7).

3. Methodology and study location

3.1. Introduction

Using the findings of the review of the literature on related theories, the research approach and design were developed to fill targeted gaps in the current debates. This chapter outlines the research approach, research design, study location and sampling, data collection and analysis tools used in the study. The full details provided in this chapter, such as the phasing of the overall research, supplement the summary information in each of the research papers.

3.2. Research approach

The research approach adopted by this study was the use of a practical, mixed methodology, appropriate for addressing the dynamic and interdisciplinary research questions (Chapter 1) (Robson, 2011) arising from Ethnopedological study (Barrera-Bassols and Zinck, 2003). The rationale for this approach was explained in detail in 1.1: it allows adequate the capture of the breadth and depth of soil management, particularly at local level. Studies examining the human-environment interface draw on methodological approaches from various disciplines, such as human and physical geography, soil science, environmental sciences, development studies and cultural ecology, and thus it is appropriate to consider a rich set of research approaches and tools (Batterbury et al., 1997). While there are scientific and quantitative recorded soil parameters, it is also necessary to consider the relatively intangible reality lived by farmers who manage this soil for their farming livelihoods. This reality captures how the soil is experienced by them, how these understandings shape their perceptions of soil fertility and result in various management strategies. Constructivism posits that perceptions reflect individual interpretations of the world and are as valid as scientific realities (Crotty, 1998). This knowledge is continually being constructed by the actions and perceptions of different social actors who manage the land (Bryman, 2012). This pragmatic approach can therefore identify methods for conceptualising knowledge as a 'tool for action' (Cornish and Gillespie, 2009).

This epistemological position shapes the research approach because it clarifies the researcher's interpretations of the research problem and ensures that observations in the field will be value-bound and unique. Therefore, to explore the research topic, one illustrative case study was selected to allow the capture of detailed understanding at local level, to allow multiple realities to be understood in context and to incorporate people's perceptions and mental mapping of the human-environment interface (Yin, 2013). This would have been difficult through a large scale science-oriented study of soil fertility, especially as the study seeks to generate new research insights that are relevant intellectually to other scales and insights about ways in which soil knowledge is constructed, compared and used to manage livelihood outcomes (Wilbanks and Kates, 1999).

3.3. Research design

A research design helps to convert research questions into a coherent project (Robson 2002) and to identify and justify the strategies and methods used. Since this interdisciplinary study draws together soil (natural) science and development (social) study, both qualitative and quantitative data from interviews and group discussions with stakeholders and quantitative data from soil analysis have been used. When used complementarily, this provided a rich data set.

The outline of the research design is presented in Figure 3-1. This shows the case study of two villages in Kitui County, Kenya. The following sections explain the issues of scale, sampling units, selection of the villages and data collection tools.

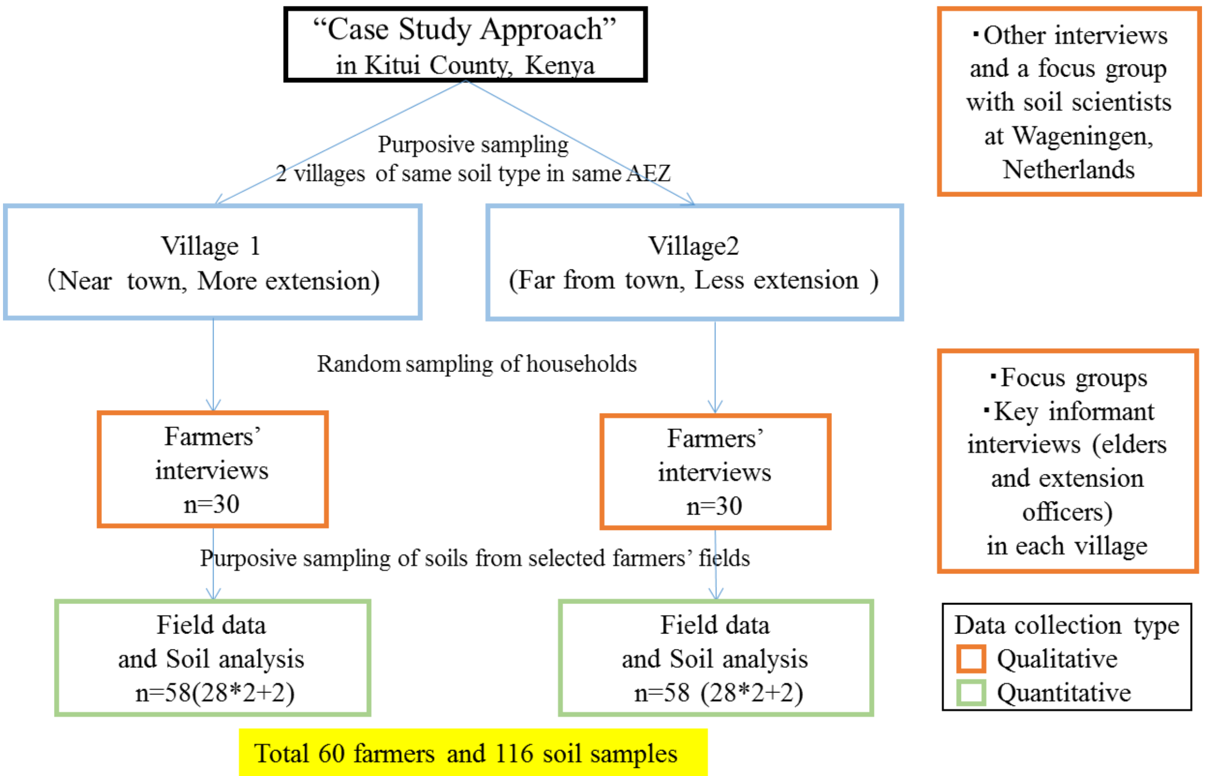


Figure 3-1 Research approach and design

3.4. Study location

This study focuses on Kenya as an illustrative case study of African soil management. It provides a valuable example for this study because, as in other developing countries, agriculture dominates the national economy (Wambugu et al., 2011) - the percentage of small-scale farmers is more than 70% (Republic of Kenya, 2014) - and Kenyan soils typically have problems with nitrogen and phosphorus deficiency, limited organic matter, and soil moisture stress that heavily affects crop production (Gicheru, 2012). Kitui County was chosen from 47 counties (The National Council for Law Reporting, 2010) because its low soil fertility causes low agricultural productivity (County Government of Kitui, 2013) and the indigenous land use system is practised there (Woomer et al., 1998). Kitui County is located about 170 km east of Nairobi (County Government of Kitui, 2013) (Figure 3-2).

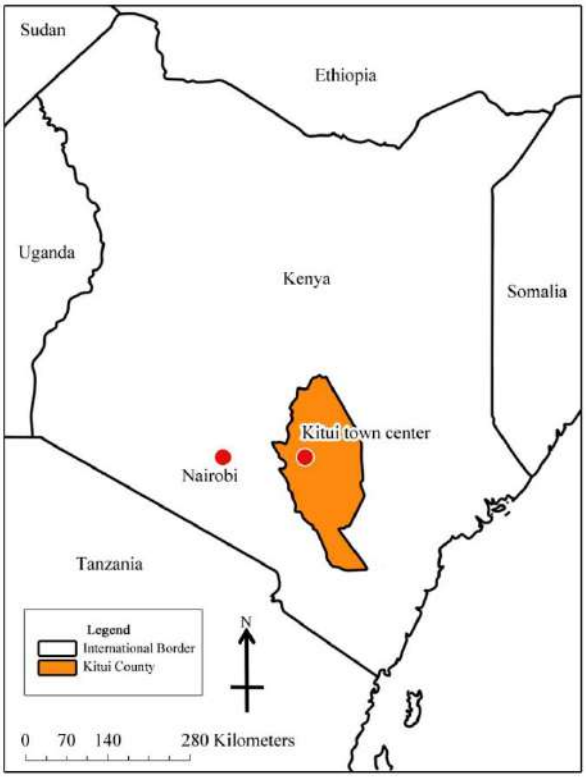


Figure 3-2 Location of Kitui County within Kenya (modified from County Government of Kitui 2013)

3.4.1. Natural conditions in Kitui

Climate: Kitui experiences a semi-arid climate. The temperature range in the county is between 14°C and 34°C; the maximum mean annual temperature ranges from 26°C to 34°C, whereas the minimum mean annual temperature ranges from 14°C to 22°C (County Government of Kitui, 2014). There are two rainy seasons: a ‘long’ season between October and December and a ‘short’ season between March and May (a local perception); comparison with a governmental publication reveals a completely opposite pattern (County Government of Kitui, 2014). Annual rainfall ranges from 250 to 1050 mm per annum (County Government of Kitui, 2014), but the period and the amount of rain are erratic and unpredictable from year to year (County Government of Kitui, 2013).

Environment: Altitude ranges in Kitui County from 400 m to 800 m and my study site is located in a small highland area which receives higher rainfall than that of other lowland areas (County Government of Kitui 2013).

3.4.2. Social conditions in Kitui

Ethnic group: The major ethnic group in Kitui County is Kamba and the Kamba language (KiKamba) is the mother language for the majority in Kitui County (KICABA Cultural Center, 2013). The Kamba have practiced livestock rearing, hunting and farming for centuries, introducing rhizome and pulse cultivation from the 17th Century (Ikeno, 1989). The population living and farming on marginal lands have increased since the 20th Century when many Kamba arrived from neighbouring Machakos, moving from poor soils with high rates of degradation (Ikeno, 1989; Karanja et al., 2017).

Government: Kitui has been a 'county' since 2010 (The National Council for Law Reporting, 2010). Inside Kitui County, the administrative units have been changed in accordance with the County Government Act 2012 (County Government of Kitui, 2014). The change of administrative units is shown in Figure 3-3). The smallest administrative unit, 'village', means a small community in a sub-location in the old system, but in the new system it is equivalent to a sub-location (or location) in the old system. At the time of data collection in 2016 the county was shifting from the old system to the new system, so the terms for administrative units used in this study follow the old county system.

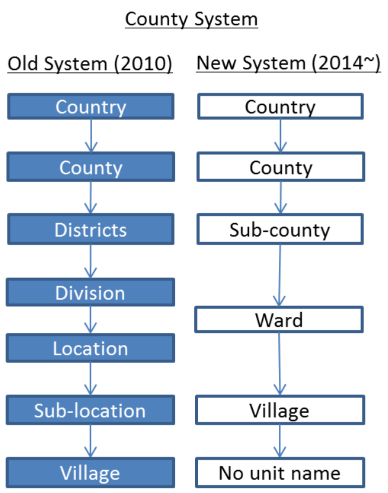


Figure 3-3 Change of administrative unit (adapted from County Government of Kitui 2014)

Population: The population density in Kitui County is smaller than the average of Kenya but the wards in which the study villages are located are slightly larger than the average for both the county and the country (Table 3-1). Nzambani, which is nearer to the Kitui centre, is more crowded than Kisasi (KNBS 2009, 2010; County Government of Kitui 2014).

Table 3-1 Population in Kitui County (adapted from KNBS 2009, 2010; County Government of Kitui 2014)

	2009 (Census)	
	Population	Density (person/km^2)
Kenya	28,686,607	49
Kitui County	1,012,236	42
Nzambani Ward	18,126	283.22
Kisasi Ward	26,759	105.52

Economic conditions: The majority of residents (87.3%) earn their livelihoods from agriculture. The Human Development Index (HDI), used in Table 3-2 below, includes life expectancy, literacy levels, school enrolment rates, and purchasing power parity (PPP) in Kitui County. Life expectancy and schooling rates are higher than the national average, but literacy levels and, especially, income are lower than those of the country generally (County Government of Kitui, 2013).

Table 3-2 Comparison of HDIs (County Government of Kitui, 2013; UNDP, 2010)

	Life expectancy (years)	Literacy levels (%)	School enrolment rate (%)	PPP (US$)
Kenya	56.6	71.4	70.5	1436
Kitui	58.9	63.2	72.3	828

3.4.3. Agriculture in Kitui

The farm types in this county comprise mixed or monoculture farming. Small-scale farmers have, on average, five acres of farmland. Farming usually depends on rain-fed cultivation (County Government of Kitui, 2013). The major food crops in this area are cereals, maize, millets, sorghum, legumes, green gram, beans, cowpeas and pigeon peas, and tuber crops such as cassava and sweet potatoes. As industrial crops, cotton and sisal are popular and horticultural crops such as mangoes, pawpaw, kale and tomatoes are cultivated, too (County Government of Kitui, 2013) (Table 3-3). Maize, green gram and cowpeas are dominant and the increase in the area used for green gram seems to be related to free relief seeds and improved drought resistant varieties (County Government of Kitui, 2013). Mango production has increased because of new varieties and export opportunities (County Government of Kitui, 2013). A substantial percentage of farmers rear animals on a small scale: young bulls, in particular, are reared for ploughing. In addition, dung from animals is used as organic manure on farms but the amount is limited (County Government of Kitui, 2013). The use of chemical fertiliser is low due to the cost (County Government of Kitui, 2013; Ralph et al., 2006) but other reasons were also surveyed in this study (see Chapter 7). Farming knowledge is deeply embedded in this rural community, and an indigenous land use system is practised, similar to that in other parts of Kenya. This land use system includes three types of enterprise areas: out-fields (away fields, comparatively remote from the home), in-fields (home gardens) and home sites (kitchen gardens) (Woomer et al., 1998). Vegetables for families are grown in kitchen gardens separately from market crops.

Table 3-3 Agricultural production area in Kitui (County Government of Kitui, 2013)

	Food					Horticultural			Total
	Maize	Green Gram	Cowpea	Beans	Sorghum	Mango	Kale	Tomato	
2012 (ha)	87970	60710	52632	31095	62530	1837	316	202	298238
(%)	29.5	20.4	17.6	10.4	21.0	0.6	0.1	0.1	100
2013 (ha)	93600	91770	87060	32294	76135	4425	173	117	386701
(%)	24.2	23.7	22.5	8.4	19.7	1.1	0.04	0.03	100

According to the local government of Kitui, the main problems for agriculture are low soil productivity, the lack of extension services, and poor market conditions (County Government of Kitui, 2013). In addition, recent more extreme rainfall events have induced soil erosion, causing land degradation (County Government of Kitui, 2013). Thereafter, other social problems such as high population pressure and poorly managed land use (including agriculture) further aggravated the damage caused by land degradation (County Government of Kitui, 2013).

3.4.4. Considerations of scale

The Agricultural Knowledge and Information System (AKIS, FAO and World Bank 2000) recognises multiple scales of influence (e.g. Global, National, County, Village) and the extent to which stakeholders (e.g., farmers, scientists, extension officers, NGO staffs) communicate across them. The focus of this study is farmers' understanding of soil and the ways in which this knowledge is communicated among farmers and between farmers and extension officers. Since there can be differences within the same location, even where soil types are similar, , the village was selected as the smallest administrative unit in the old county system (see Figure 3-3). For the data collection at village level, the study was interested in household and individual farmer to observe the difference of knowledge and management among farmers. The field practices were usually decided based on the dissemination of knowledge of all household members in the study area. This is detailed later in section 3.5.2.

3.4.5. Selection of study villages

Two villages in Kitui County were selected by purposive sampling (Tongco, 2007) in order to allow the study to represent locations with similar environmental conditions but different social conditions.

For the selection of suitable villages, four criteria were used:

(a) location in the same soil type (Um19), based on the national soil map, and in the same Agro-Ecological Zone (AEZ) (marginal cotton zone (vs/s+s/vs));

(b) the majority of villagers engaged in small-scale farming;

(c) different distances from Kitui town centre and different frequency of communication with extension workers (that in the closest being higher than in the more remote location);

(d) no active NGO activity or agricultural extension project.

The reasons of those criteria are as follows. (a) soil types indicate general soil properties, so they are assumed to affect farmers' perception of soils and fertility, and AEZ represents the area's climate conditions. Therefore, it was important to take data from the same high-level soil type and AEZ to reduce excessive variation caused by natural factors and focus on variation caused by social and management factors. (b) This study focuses on soil fertility in farmers' fields and its effect on small scale farmers' decision-making. (c) The distance from town centre can affect the level of extension service, and, therefore, access to scientific knowledge (Anderson 2006). (d) In order to focus exclusively on the influence of the distance from town and the level of national extension service on the farmers' soil management, villages included in other projects were eliminated from this study. A national soil map, AEZ map (Sombroek et al. 1980), and road map (WFP 2007) of Kenya were processed on ArcGIS to identify the potential area and then shown on Google Earth.

In January 2016, 11 sub-locations in Kitui County were visited by the researcher in order to explore village locations and to collect background information about the villages and more generally about Kitui farmers' livelihoods (Scoping 1) (Table 3-4). After that, three sub-locations (Kitumbi, Chuluni, Itoleka) were selected for a more focused exploration (Scoping 2). They were selected because they were located in the dominant soil type for Kitui County and therefore it was possible to get information about the local soil classification. Chuluni was selected as one sub-location because it had standardized geological and soil variation. The village of Kavuti within Chuluni sub-location was selected as Village 1 because it had no record of special external projects on soil management.

A third period of scoping (Scoping 3) was conducted to explore a potential comparative Village 2 from the same soil and Agro-Ecological Zone (AEZ) areas but with different social conditions (e.g. further from the settlement of Kitui and where there may have been less influence from the extension services). Based on discussions with an officer in Ministry of Agriculture in Kitui County, two sub-locations (Kitungati and Mosa) were proposed for Scoping 3. In the two locations, Kitungati was selected and six villages were visited as Scoping 4. Kitambasyee was selected as Village 2 because there was the greatest degree of difference in social factors (e.g. income source and extension services) between this village and Village 1.

Table 3-4 Initial scoping activities for village sampling

Scoping phase	Purpose	Contents of interview questions	No. and types of participants (per visit) (positions of attendants)	No. of visits	Name of visited places (unit)
1	1st Village selection	●Place to buy farming materials and market ●Transport toward town centre ●Extension and Group activity	1~3 (chiefs, assistant-chiefs and elders)	11	Museve, Waluku, Kitumbi, Kasyala, Mulago, Chuluni, Muluku, Iiani, Itoleka, Katulani, Kathungi (sub-Location)
2		●Dominant local soil types ●Characteristics of fertile and low fertility soil ●Soil management ●Field-visit	3~4 (elders)	3	Kitumbi, Chuluni, Itoleka (sub-Location)
3	2nd Village Selection	●Place to buy farming materials and market ●Transport to town centre ●Extension and group activity	2 (chiefs, assistant-chiefs or elders)	2	Kitungati, Mosa (sub-Location)
4		●Dominant local Soil types ●Characteristics of fertile and low fertility soil ●Soil management ●Field-visit ●Extension and Group activity	1 (elders)	6	Kitambasyee, Ngusyini, Kitungati, Mabiani, Itumbule, Kaukuni (Village)

Village 1 (Kavuti) and Village 2 (Kitambasyee) were finally selected (Figure 3-4). The national soil map (Sombroek et al., 1980) identifies the study area as Um19: 'well drained, moderately deep to deep, dark reddish brown to dark yellowish brown, friable to firm, sandy clay to clay; in many place with top soils of loamy sand to sandy loam (ferralo-chromic/ orthic/ ferric ACRISOLS; with LUVISOLS and FERRALSOLS)' (p25). Acrisols and Luvisols are determined by the existence of Argic horizon (accumulation of clay) and classified by CEC (less than 24 $cmol_c\ kg^{-1}$ is for Acrisols and more than 24 $cmol_c\ kg^{-1}$ is for Luvisols) and base saturation (less than 50% for both) (IUSS Working Group WRB, 2015). Ferralsols are determined by a red colour and low activity clay minerals (IUSS Working Group WRB, 2015). The bedrock is marked as area *Xg* on the Geological map for Kitui (Mine and Geological Department Kenya colony North-West Quadrant, 1954) and described as 'Microcline-oligoclase-biotite-hornblende migminte with biotite anplibolite schlieren granitic sheet and vien reticulation' (Appendix 2).

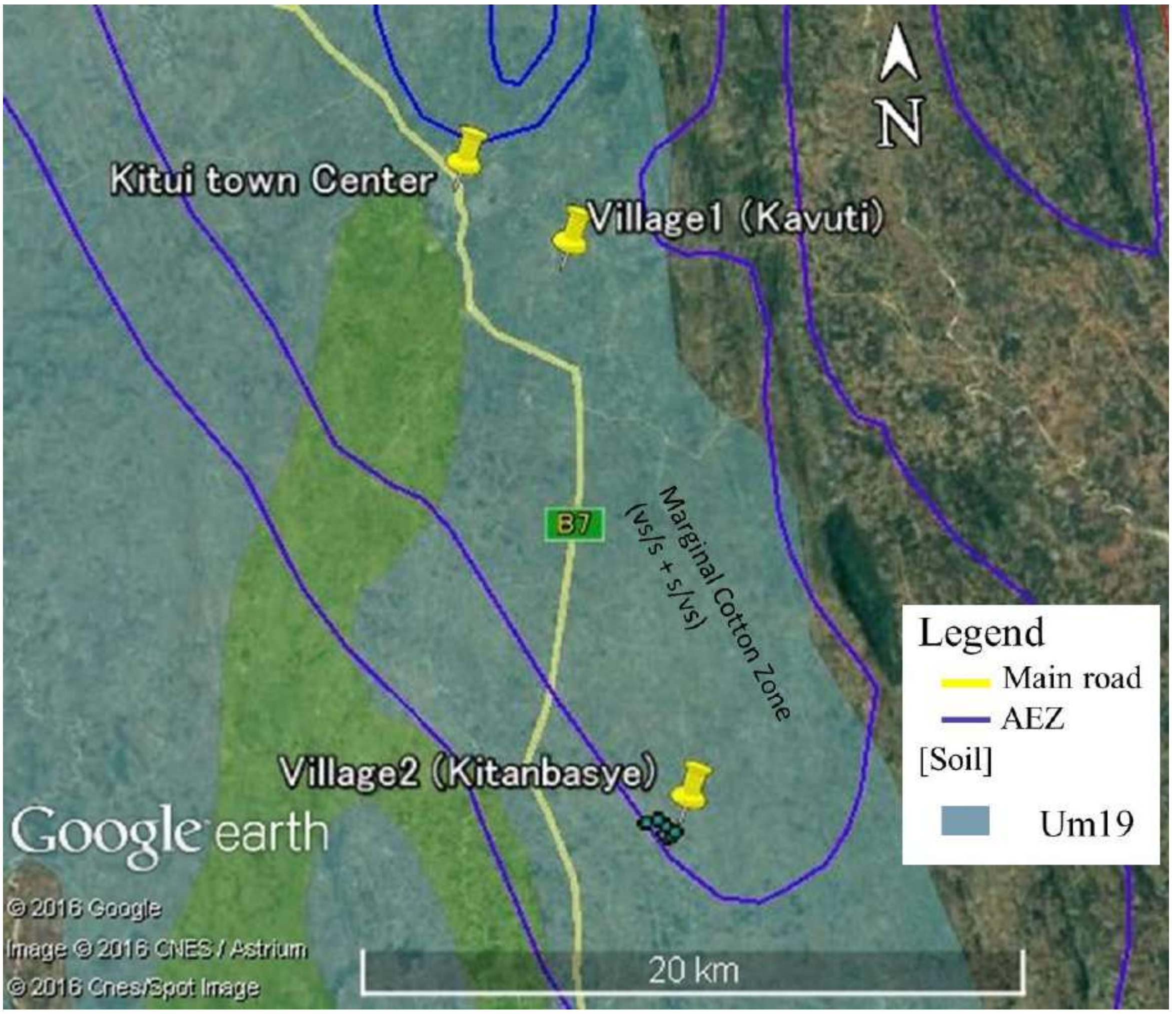


Figure 3-4 Location of Study Site: the two study villages are located in the same soil type (Um 19) in the National Soil Map and the same AEZ zone (marginal cotton zone (vs/s+s/vs)) (Google Earth, adapted from Sombroek et al. 1980 and WFP 2007)

GPS data showed similarities in elevation (1180m in Village 1 and 1000m in Village 2) and in field slope, from flat to moderately steep (0 to 25%) (Soil Survey Division Staff 2017). Village 1 was located near Kitui town (4.5 km) with historically frequent communication from Agricultural Extension officials - the village was located near the chief's office where 'balaza' (public meetings) are held, a Ministry of Agriculture official lived in the village, and some farmers had relatives or friends who engaged with volunteer extension activities. Village 2 was located 20km from the town (which could take more than 2 h two hours to walk), access to other modes of transport was limited, and there was limited communication with Agricultural Extension officials.

3.5. Research methods and tools

The research methods and tools were chosen according to the types of data needed for each objective of this research (Table 3-5). For objective 1, data on both farmers' qualitative and soil scientific (quantitative) knowledge of soil fertility was needed and interviews and focus group discussions with farmers and soil analysis were used. For objective 2, the linkage with structured concepts of soil fertility, data were collected by using a causal diagram to reflect farmers' real perceptions of soil with different fertility and its differences among farmers. Finally, the data from farmers and the comments from extension officers were collected, mainly as narratives, through individual interviews that contributed to understanding of individual external and internal decision-making factors (objective 3).

Field research was conducted from January 2016 until October 2016 in Kenya (see the detail in the timeline in Figure 3-5). This research used a range of methods: social science data was collected from interviews and focus groups with stakeholders. Soil science data was collected using field measurement and further laboratory analysis. This section explains the ethical considerations when considering a range of methods, defines the units for sampling, and finally provides details and reflections on the specific tools adopted.

Table 3-5 Tools for data collection

Objective	Related theories	Needed data	Tool
1) understanding the relationship between farmers and the scientific knowledge of soil fertility	-Ethnopedology (Barrera-Bassols and Zinck, 2003) - AKS (Röling, 1988) -Hybrid knowledge (Barrios et al., 2006)	-Indicators of soil fertility -Location and scale of the best and the worst soil in farmers' fields	Structured questionnaire
		-Historical change of soils, land management and lifestyle	Focus group
		-Soil physicochemical parameters	Soil analysis
2) understanding the deeper structure of indigenous knowledge systems concerning soil fertility		-The reasons for crop selection for fertile and low fertility places	Causal diagram
		-Soil scientists' perception of soil fertility	Focus group and In-depth interview
3) to understand the flow of knowledge systems through information sources, learning and decisions made about field management and adaptation to risks from climate extremes	-Communication and extension (2.4.1) -Social learning (Miller and Dollard, 1945) -Decision-making factors (Ajzen, 2002) -Process of adoption (Urope et al. , 2010) -AIS (Hall et al., 2006) -Soil and climate change (Osbahr and Allan, 2003)	-Livelihoods data -Management practices -Change of management for drought and excessive rain -Source of management information -Reasons for each field management decision	Structured questionnaire, Follow-up interview, Seasonal calendar
		-Extension officers' comments	In-depth interview

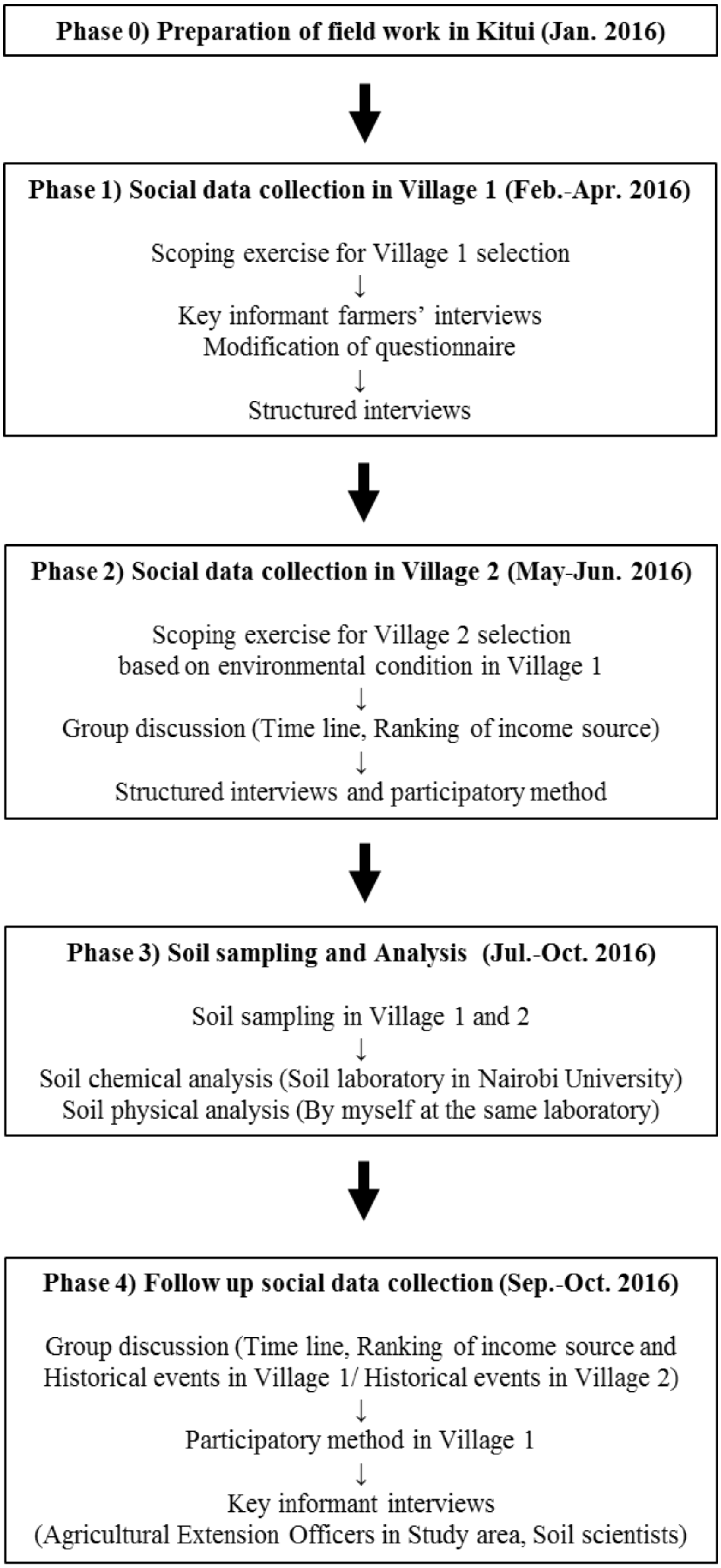


Figure 3-5 Timeline of activities carried out during fieldwork

3.5.1. Ethical issues

Ethics is an essential element of social study and fieldwork. It is important to explain carefully to participants and local government officials the rationale for the research (what, why, with whom, when, how) and to explain and discuss through iterative engagement their rights and interests (Leavy, 2017). All data collection in Kenya was conducted under a research permit from the National Commission for Science, Technology and Innovation (NACOSTI), through affiliation with the Department of Agricultural and Resource Economics in Jomo Kenyatta University of Agriculture and Technology. The tools and approach for engagement were approved through the Research Ethics Committee at the University of Reading. Before starting the data collection, consent from participants was obtained by signing an information and consent sheet (Appendix 3) about taking pictures, note and voice recording, protecting their identity, treating data including where and for how long data would be stored and who had access to the data, and considering their role within the research process. All participants in this study approved the recording audio and written data and usage of data for this thesis.

3.5.2. The units of analysis: defining a household and selection of participants

One individual participant was purposively selected from each sample household. Random sampling was used to select households within each village. Although the meaning of a 'household' is different to different people in different places (Chant and Campling, 1997), for the purposes of this study, a household was defined according to local perceptions of a household unit as "a group of family members who use the same kitchen" (personal communication with farmers). Based on this definition, household lists for Village 1 and Village 2 were generated by the 'elder', an official reader of each village. The elders also assisted with the selection of key informants in each village. For the study, approximately 50% of the total number of households in each village were randomly sampled and the person who made decisions about the management of their fields (usually the household head or his wife) was purposively selected as the interviewee for each household. The total number of farmers sampled was 60 (30 in each village). Within each farmer's fields, soil samples were taken from two sites, evaluated by the farmers themselves as either the most or the worst fertile. It should be noted, however, that although soil samples were collected from all sampled farmers' fields, four participants (two in each village) gave each of their paired samples the same evaluation. Therefore, the total number of soil samples yielding appropriate scientific data was 116. In addition to that, where the creation of mental models is concerned, the number of sampled farmers with fertile soil was 58 and with low fertility soil was 56, due to the absence of a farmer who was busy during the data collection by causal diagram at Village 1 in the Phase 4 period.

For focus group discussions and key informants' interviews, purposive sampling was used to collect targeted data from specific farmers and extension officers. This is detailed later in section 3.5.3.

3.5.3. Social science data collection from farmers

Social science data from Kitui farmers was collected mainly using a structured questionnaire and follow-up guided interviews with farmers and external stakeholders to increase the quality of the recorded response and allow use of visual aids (Robson, 2011). In addition, focus group (Robson, 2011) and participatory methods (Galpin et al., 2000) were included. I conducted all data collection personally, with a trained translator for most farmers within KiKamba and English and in English for external stakeholders. Table 3-6 shows the outline of the social science data.

Table 3-6 Outline of Social science data collection in Kitui County

Collection method	Data Category	Source	No. of participants
Structured and follow-up interview	Livelihoods data, Perception of soils and their management, Sources of information	Sampled farmers	60
Participatory method	The reason for crop selection for each place, how to learn the place to plant	Sampled farmers	59
	Seasonal calendar		30 (Village 2)
Focus group	Historical change of soil, land management and their life	Elder farmers	10 (5 in each village)
	Timeline: Extension and Historical event	Mainly male farmers	23 (5 in Village 1 and 18 in Village 2)
	Ranking: Livelihoods strategy		
Key informant interview	Agricultural extension	Extension officers	2 (1 in each village)

Structured Interview for Individual Farmers

When collecting both quantitative and qualitative data for the ethnopedological study (Barrera-Bassols and Zinck, 2003), the structured questionnaire and follow-up guided interview were chosen for individual data collection (Robson, 2011) and pre-tested before use. Interviews were conducted with 30 farmers in each village (total 60). Interviews were conducted following a questionnaire including a mix of standardised questions with pre-defined answer options and open-ended questions (Appendix 4), and additional information from interviewed farmers was recorded in a field notebook. The interview included six parts: 1) livelihood data; 2) indicators of soil fertility; 3) location and scale of the best and the worst soil in farmers' fields; 4) management practices for different plots; 5) change of management based on drought and excessive rain; and 6) sources of management information and learning (Figure 3-6). In addition, 7) the reasons for the decisions made for the management of each field were collected in follow-up interviews (Appendix 5c).

Figure 3-6 Interviews with individual farmers. (A translator in the centre translates my question into KiKamba for a farmer on the right. An elder of the village on the left guided us to the interviewed farmer's place.)

Participatory Methods for Individual Farmers

In addition to structured interviews, some participatory methods were used, because visualization during discussion can help to clarify farmers' information about their farm management and livelihoods strategy (Galpin et al., 2000). Causal diagrams (Galpin et al. 2000, Appendix 5a) were used for the creation of farmers' mental models of soil fertility perception (Prager and Curfs, 2016). 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. The same questions were repeated for fields on their farm with 'the worst fertility'.

Seasonal calendars (Pretty et al. 1995, Appendix 5b) were used in Village 2 because it seemed the best way to visualize and get accurate information. However, these were time consuming and no big difference among the farmers' calendars emerged, so similar questions were asked directly in the follow-up interview in Village 1 (Appendix 5c). The data from seasonal calendars was also used in Chapter 7.

The contents of the causal diagrams and seasonal calendar (along with an alternative structured interview sheet) are shown in Appendix 5. Information was informally checked during field walks around the villages and with some farmers on their fields. This provided an opportunity for observation and triangulation of data.

Focus Group Discussion

Focus group discussion was chosen for the collection of general information about the study site (Appendix 6). This method provided a rapid insight into soil management practice and was complementary to the individual participant information (Robson, 2011). During questionnaire interviews in Village 1, it was recognised that the answers about information sources, decision-making and soil conditions were closely related to historical social and environmental changes in the villages. Therefore, two types of focus group discussion were conducted to collect general background information about each village. The first one was about historical change in soils, land management and lifestyle in each village. Purposive sampling (Tongco, 2007) was used to gather five elder farmers (five farmers per village, with an age range between 53 and 83 years old) who had knowledge of historical changes in soil and agriculture. The second discussion involved establishing a timeline (Department Planning and Development, 2004) of extension and events, and listing and ranking (Pretty et al., 1995) the main income sources and expenditure in each village in order to understand livelihood strategies. This discussion was first conducted with 18 participants (Figure 3-7) in Village 2. Notably, those who talked about specific years and money were male. Following this experience, only five male farmers were invited for the focus group on this topic in Village 1. It was important that the researcher was able to allow time for conversation and to control gender and cultural power dynamics to allow multiple voices to contribute to the discussions.

Figure 3-7 Focus group discussion in Village 2

Key Informant Interview

Agricultural extension staff were knowledge brokers between new technology and farmers. Extension officers' knowledge and communication style with farmers are known to influence the construction of farmers' hybrid knowledge (Anderson, 2006; Muyanga and Jayne, 2006). Structured interview with two agricultural extension officers in charge of each village were conducted, exploring their work, activities and problems in communication with farmers (Appendix 7).

3.5.4. Social science data collection from soil scientists

To create the soil scientists' mental model, soil scientists who had experience of soil research in East Africa were purposively selected for data collection, to ensure they had experience of the types of ecosystems in Kitui. The data was collected during the Wageningen Soil Conference at Wageningen University, the Netherlands, in August 2017. In total, eight soil scientists with experience of soil research in East Africa participated: five early career and three established, six males and two females, six Africans and two Europeans.

Using participatory methods for reflecting fundamental concepts for soil fertility, through a group discussion, five scientists created a causal diagram (Galpin et al. 2000) of soil fertility. All were doctoral candidates: three Ethiopians, one Zambian and one who studied in Kenya, but came from the Netherlands. The scientists were all asked to consider their response in the context of East African soils where the dominant crop was maize, like Kitui. First, they were asked the guiding question: "How (or by what factors) do you recognize the soil as fertile?" They wrote their answers on post-its and put them on a big sheet of white paper. Next, they were asked, "Please actively draw the lines to show the links between these factors." Finally, the causal diagram with linked concepts about soil fertility was made.

In-depth interviews followed with three additional soil scientists (a professor from the Netherlands, a professor from Ethiopia and a director of a research institute in Kenya), who also had experience of soil research in East Africa. This was done in order to add further opinions to the mental map. They were shown the diagram made in the workshop, and asked, "Are there any items you want to add or remove from this diagram?" The additional information arising from the interviews was added to the diagram.

3.5.5. Soil science data collection

Soils and field data were collected from each of the two sites. 60 farmers selected the most and the worst fertile soils in 'their cultivated fields', giving up to 116 sampling locations in total. The definition of 'their cultivated field' in this study was "the fields that the interviewee owned or rented and that were his/her responsibility, not including fields owned by any other family member". This is because households which owned many plots of land sometimes divided ownership between their members, so that the people in charge of the land, rather than the heads of the households, had the right to make decisions about it. In addition, the sizes of the sampling portions varied according to farmers' perception of boundaries between different kinds of soil. For example, some farmers discriminated between soils even in a small field, but others felt that the same soil condition extended over the whole of a big farm.

Soil Sampling and Field Data Collection

Soil samples were collected in August 2016 from the best and the worst fertile places in fields, as identified by each sampled farmer. The sample collection took part just after harvest and the last short rains in fields that had not yet been prepared for next growing season. This was considered good timing for evaluating baseline soil nutrient status and soil structure with minimal impact from additional inputs. Surface (10cm) soil samples were taken from 10 points within each field and bulked up to make single composite samples of 500g (Figure 3-8). The sampling depth was set at 10 cm because of the hardness of the soils and the length of time necessary for taking samples from 10 points for standardization. The total number of soil samples was 116, 59 from the best fertile locations and 57 from the worst fertile places. This was because four farmers had just one farm: one of them evaluated their field as not fertile only while the other three evaluated their fields as fertile only. During soil sampling, other field data were collected, including the area of the field sampled, local soil names, the location by GPS, and the size of the soil sampling area; the slopes of terraces and fields were measured by a clinometer and visual observations were taken of the amount of stone on the surface.

Figure 3-8 Soil sampling with a farmer's guide (on the right)

Soil Laboratory Analysis

Soil analysis focused on the physical and chemical properties of soils, which are used as general indicators of soil fertility in other ethnopedological papers (e.g. Murage *et al.*, 2000; Kamidohzono *et al.*, 2002; Osbahr and Allan, 2003; Mairura *et al.*, 2007). All the analysis was done in the soil laboratory at Nairobi University (Figure 3-9).

Soil physical measurements were carried out on the field samples. Colour of soils (wet and dry) was determined using a Munsell colour chart and named using the guide at [https://logiteasy.com/free-tools/munsell-calculator.php.](https://logiteasy.com/free-tools/munsell-calculator.php) Texture was determined by the ball and ribbon method (Thien, 1979). Water Holding Capacity (WHC) was measured by a simplified method from the soil laboratory at Reading University. The weights of saturated, overnight airdried and oven dried soils were weighed for the calculation.

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

For the chemical parameters, pH in H_2O (1:2.5) was measured using a glass electrode pH meter (Carter et al. 2008) and electrical conductivity ($EC_{1:1}$) was measured using a conductivity meter (Richards, 1954). The Total Organic Carbon (TOC) was determined by the Walkley-Black method (Walkley 1947), and the Kjedhal Method (Okalebo et al. 1993) was used for Total-Nitrogen (TN). Nitrate-Nitrogen (NN) was extracted with 2.0 M KCl (10g soil in 100ml KCl) and measured by 0.01 N H_2SO_4 using an Auto-Titrator (Keeney and Nelson, 1982). Available Phosphorus (AP) was measured by Mehlich 1 (Mehlich, 1953; Nelson et al., 1953) using the double acid reagent (0.05 N HCl in 0.025 N H_2SO_4) as an extractant (5g soil in 50ml double acid). Exchangeable Potassium (K) and Sodium (Na) were extracted by 1M ammonium acetate (5g soil in 50ml ammonium acetate) and measured using an atomic absorption spectrophotometer. Cation Exchange Capacity (CEC) was assessed with the same extractions after exchangeable cation using the semi-micro distillation method (Lavkulich, 1981). All soil physical and chemical analysis methods are described in Table 3-7 and the detailed process of analysis is shown in Appendix 8.

Figure 3-9 Soil Laboratory at Nairobi University

Table 3-7 Soil Chemical Analysis Methods

Item	Method	Reference
pH	Soil: Water =1:5	Carter et al. (2008)
EC	Soil: Water =1:1	(Landon, 1984)
TOC	Walkley and black method (wet combustion)	Walkley (1947)
TN	Kjedhal Method	Okalebo et al. (1993)
NN	Extraction of NO_3^-N and NH_4^-N with 2.0 M KCL	Keeney and Nelson (1982)
AP	Mehlich 1	Mehlich (1953); Nelson et al. (1953)
Exchangeable K and Na, and CEC	Ammonium Acetate method	Lavkulich (1981)

3.5.6. Data analysis

After collecting data, all written data was digitalized and sorted by sample and by question on Excel 2016. Qualitative data was coded first, then categorized and ranked for quantification. Farmers' and soil scientists' mental models were created manually, based on the coded data. Statistical analysis was used to see the significance of the difference and the correlation between farmers' perception on soil fertility and soil physiochemical data (Pearson's chi-squared test and General Linear Model (GLM)) and to classify the households by different livelihood strategies (cluster analysis).

Coding and quantification

Qualitative data from the interviews and participatory method was analysed using thematic coding (Coffey and Atkinson, 1996), using SPSS 21.0, Excel 2016 and Word 2016 to reveal the share of respondents who mentioned soil names, soil characteristics, the location and scale of the best and worst soil in farmers' fields, and their practices and reasons at least once. Narratives from the different forms of analysis were then organised to explain identified patterns.

Mental model creation

To compare different knowledge systems, recent work by Prager and Curfs (2016) has demonstrated a mental model approach. The mental model approach was developed in psychology and education studies (Axelrod, 1976) but it has attracted attention in natural resource management study fields as a means of exploring the interactions of humans and their environment (Jones et al., 2011) and relationships among stakeholders (Özesmi and Özesmi, 2004) Mental models have been used to compare scientists' and farmers' understanding of the ploughing of olive groves in south-western Spain (Prager and Curfs, 2016). Both view tillage as important to reduce fire risk. The models showed that farmers perceived additional positive impacts, involving the reduction of competition for nutrients and water, whereas scientists tended to focus most on soil degradation and production losses. One type of mental model is the 'semantic web' (Novak and Growin, 1984), where a semantic web diagram shows 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). Visualisations through diagram-based representations of mental models provide a simple and understandable tool to communicate these types of similarities and differences between types of farmer, and between other stakeholders, including scientists or government officials, who also influence land management choices (Prager and Curfs, 2016; Wood et al., 2012). The mental map has rarely been used in soil science research in Kenya, and it has the potential to enhance communication between various stakeholders by visualization of other mental models which connected to active collaboration for sustainable soil management. The processes of the creation of farmers' and soil scientists' mental models are different due to time and sample limitation for the soil scientists' mental model;

Farmers' mental models: the two aggregated sematic webs of 59 farmers' perception of fertile and low fertility soils were created. 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 dominated answer was selected as the representative concepts. KH coder- word-association software (http://khc.sourceforge.net/en/) which has been used in the analysis of public opinion, mainly in Japan (Maeda, 2015; Tsukada and Morita, 2018) - was used for counting the share of respondents in total and per each village and checking the connection between the concepts. The links between the representative concept were connected with the manually selected relationship terms, according to the farmers' narrative data. The same process was repeated for the creation of the sematic web of low fertility soil. The category with the share of respondents for fertile soil was shown as an example of qualitative data coding in Appendix 9.

Soil scientists' mental model: After the data collection, the linked concepts on the created causal diagram were sorted and rearranged manually to create a sematic web. The relation terms which connected the concepts were selected from the voice recorded data in the discussion and interviews, then the soil scientists' mental model of fertile soil was created. Some narratives during the workshop and interview were transcripts from recorded data, shown as supporting information about their mental model.

Statistical Analysis

After quantify the farmers' answers by coding, statistical analysis of the quantitative data for observe the relationship between farmers' and soil scientific evaluation of soil fertility was performed using Minitab 17. The Pearson's chi-squared test was used to assess differences between 1) villages and farmer-selected locations of the best and worst fertility soil, 2) farmers' soil fertility evaluation and local soil name, 3) villages and soil texture and 4) villages and locally determined soil colour classifications. GLM was used to explore differences between the physicochemical data and farmers' evaluations of soil fertility. A multiple comparison approach was used to compare relationships between soil physiochemical data and soil texture/locally determined colour classifications. Data were checked for normality and equal variance prior to statistical tests. The results of TOC, TN, NN, AP, K, Na, CEC and EC took the log of the data first and then fitted the GLM to the logged data to improve the normality of residuals from the fitted GLM model.

For understanding the influence of livelihoods for farmers' decision-making on their management of fields, 60 households were classified into four groups with similar livelihood strategies using cluster analysis within SPSS 21.0, and particular focuses on income-earning aspects of livelihood, following the approach of Iiyama et al. (2008) and Freeman and Ellis (2005). Cluster analysis was performed by the Ward method using the contribution rate of each income source (food crops, fruit and vegetables, livestock, and off-farm activity) to total income, types of off-farm income (regular employment and casual labour, remittance was divided into the two categories based on the periodicity), the number of cows/bulls owned and the number of cultivated fields. Types of income sources were analysed for amount and timing. Other assets were included in the analysis, such as livestock and land. Cows and bulls were treated as main long-term assets. The number of cultivated fields had a positive correlation with the total cultivated area: many farmers in the study area did not know the exact values. On SPSS 21.0, the collected data was sorted and the types of off-farm income was converted into numerical values (regular employment: 1 and casual labour: 2). To balance the volume of data on the ward method, standardization option was selected in SPSS operation.

3.6. Reflections as a researcher on fieldwork in Kitui

The data collection in the communities proceeded successfully. It took time to receive the national research permit from NACOSTI due to the problem with the paperwork, but the permit made it easy to communicate with officials. They welcomed me as a newcomer bringing new information to the communities. Before data collection, I discussed this study, giving detailed explanations of its aim, my sampling strategy, the contents of the questionnaire, and the conduct of the group discussions and the soil analysis, as well as the outcomes and benefits for participants, with my research partner, who also did the translation. Thanks to her understanding, she was able to explain this research to the farmers, and reduce their scepticism. The interviews were time consuming and the participating farmers needed to stop their work for the data collection. Finally, I collected all the data that I wanted.

The social scientific survey is quite new for me, since I was trained as a soil scientist; this was also a learning process that made me more open to other views and ideas in social science methodology. Collecting farmers' narratives about soil management and their lives provided a newly enriched social context for my soil physiochemical analysis data. That was the world which I had wanted to see since I did soil sampling in the experimental field in Egypt for my MA dissertation. I stayed in the elders' houses in each village during data collection and it brought me close to the farmers. I understood their daily life and its relationship with soil fertility better than if I had just conducted interviews. I also talked a lot with farmers about the UK and Japan. These informal knowledge exchanges improved the level of practical information on both sides. However, I could learn only a few words of the local language during my 10 months' stay and communication remained limited. Collaboration with anthropologists who understand the local language and have extensive background knowledge would improve the quality of the content of ethnopedological research.

The cultural norms about women's roles in my study location seemed to have changed. Although the right of male heads of households to make decisions still remained, there were many active women who did salaried work, owned grocery shops, attended various meetings and were the beneficiaries of development or charity projects. Women's responsibility for decision-making on agricultural practices also increased with the absence of men for off-farm income work in the town or in Nairobi. I did not experience any expression of contempt during my fieldwork as a foreign female researcher. The elder in Kavuti told me that "the modern age is much better than before. When I was a girl, women needed to obey all men. I could not go to school because it was said that it was the place for prostitutes. I am happy to see a girl like you doing research".

In addition to the successful data collection for my PhD thesis, my big challenge was leaving the benefits of the survey to the communities. When I did my research internship in the same area in 2010-2011, a farmer asked me, "What is the benefit of your survey for us?" I could not offer any direct benefit in my answer. One of the problems of academic research is that researchers collect data but they do not feedback the results to their fields. Lack of politeness also increases local distrust of people and knowledge from outside. Therefore, I promised to deliver the results of the soil analysis to the participating farmers, so that knowledge of the current status of their soil could inform their next management decisions. At the end of fieldwork, I delivered the soil analysis data by hand to each participant, and gave an explanation: they expressed their happiness in knowing new things about soil.

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

Abstract

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

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

4.1. Introduction

Soil is the basis of life for both human food security and the building of the natural environment. Knowledge of soil fertility is basic information, essential for improving soil productivity and identifying 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 et al., 2018). Criticism of the limited effectiveness of implementing top-down technology and scientific information transfer including soil science knowledge through extension services has led to increasing emphasis on the value and integration of indigenous knowledge held by farmers (Barrios and Trejo, 2003; Berazneva et al., 2018; Guzman et al., 2018; Richelle et al., 2018). A fundamental presupposition of Eurocentric science is that "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 from experiences, society-nature relationships, community practices and institutions, and passed down the generations (Brokensha et al., 1980).

Farmers observe and evaluate their local soil experience to make everyday land management decisions (Guzman et al., 2018; Rushemuka et al., 2014). Integrating indigenous 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 points out that effective external interventions are best achieved "*once we know what they (farmers) already know, and what else might be most useful to add to their store of knowledge and tools*" (Walker et al. 1995: 236). 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, or other stakeholders whose understanding of soils is based on scientific knowledge (e.g. extension officers), is not easy due to the ways in which indigenous 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 2-1). 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: 125-126) 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.". Two-way communication between farmers and scientists and/or extension officers is essential to plan suitable soil conservation and land management options (Oldeman, 1992).

The starting point of soil fertility evaluation by farmers and soil scientists is the same: the performance of crop growth (Murage et al., 2000; Vilenskii, 1957). In addition, farmers also explain the characteristics of fertile or low fertility soils, mainly by visual and morphological features, such as texture and colour, which are used as universal criteria of soil fertility (Mairura et al. 2007 in Central Kenya; Kamidohzono et al. 2002 in West Sumatra). Even though they have the same starting point, farmers and scientists do not have the same attitude to evaluating soil fertility. Soil scientists measure soil as a natural resource using quantitative analysis, while farmers evaluate soils as part of their daily experience in the field (Ingram et al., 2010). Farmers have more 'know-how' or 'practical knowledge' about soil, and scientists have more scientific knowledge or 'know-why' about soil (Ingram, 2008). These differences can be categorized into three main parts: perception of other environmental information; spatial scale; and timescale.

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

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

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

The implications of these differences have not been clearly reconciled within the literature. In particular, are farmers observe similar aspects of structure and function as classified in soil science, and if so, what can we learn from farmers' soil fertility evaluation for hybrid knowledge construction? To address this challenge, this study will: examine the similarities and differences between farmers' qualitative evaluation and soil science quantitative analysis for soil fertility classification and explore how the location of soils (e.g. villages and distance from home) influence farmers' evaluation of soil fertility. Location of soils reflects the effect of social and environmental differences and historical background of settlement. By examining these different approaches through a case study from Kenya, the study will be able to highlight the potential value of improved awareness about local historical narratives of soil fertility, which reflect holistic knowledge systems and livelihood experience. It also has implications for developing local tailor-made soil assessment systems through enhanced communication between farmers and soil scientists and/or extension officers.

4.2. Approach and methods

4.2.1. The role of the case study approach

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

Within Kenya, the research focused on Kitui County, located about 170 km east of Nairobi (Figure 3-2). Kitui county offered the opportunity to select contrasting soil types with the same climate and land-use practices. The first rationale for selecting this county is the identification of contrasting soil types as recorded on the soil map for the region, resulting from the metamorphic bedrock and variation of slope (Mine and Geological Department Kenya colony North-West Quadrant, 1954; Sombroek et al., 1980). The area has a semi-arid climate, with temperature between 14℃ to 34℃, and two rainy seasons, a 'long' season between October and December and a 'short' season between March and May, according to local perception, which is opposite to the pattern in the governmental publication (County Government of Kitui, 2014). The exact period and amount of rain is erratic and unpredictable from year to year, with annual rainfall between 250mm and 1050mm (County Government of Kitui, 2013). The major ethno-cultural group is the Kamba, and KiKamba is spoken by most people in Kitui County (KICABA Cultural Center, 2013). The Kamba have practiced livestock rearing, hunting and farming for centuries, introducing rhizome and pulse cultivation from the 17th Century (Ikeno 1989). The population living and farming on marginal lands have increased since the 20th Century when many Kamba arrived from neighbouring Machakos, moving from poor soils with high rates of degradation (Ikeno, 1989; Karanja et al., 2017). Today, 87% of residents earn their livelihoods from agriculture using an average 2ha farm, with additional income from salary, casual local labouring and migrant work (County Government of Kitui, 2013). Both mixed and monoculture rainfed farming are practised with maize, legumes, green gram, cowpea and pigeon pea as the main crops. Small numbers of livestock are owned and the manure is used to fertilise the fields, although the amount is limited. The use of chemical fertilizer is low because most farmers cannot afford to buy fertilizer (County Government of Kitui, 2013; Ralph et al., 2006). The second rationale for selection was the deep cultural rural farming knowledge, including the practice of a traditional land use system, similar to other parts of Kenya. This system includes three types of enterprise areas: out-fields (away-field), in-fields (home garden) and a home site (kitchen gardens) (Woomer et al., 1998).

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

Visits to villages to triangulate the soil data were conducted and Village 1 (Kavuti) and Village 2 (Kitambasyee) were selected to represent locations with similar environmental conditions but different social conditions (Figure 3-4). GPS data showed elevation was similar (1180 m in Village 1 and 1000 m in Village 2) and field slopes were similar, being flat to moderately steep (0 to 25%) (Soil Survey Division Staff, 2017). Village 1 was located near Kitui town (4.5 km) with historically frequent communication from Agricultural Extension officials - the village was located near the chief's office 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, although due to limited transport it could take more than 2 h to walk, and there was limited communication with agricultural extension officials.

4.2.2. Data collection: farmer knowledge

Data was collected between January and October 2016. To understand the relationship between farmers' knowledge of soil fertility and soil physicochemical parameters, a mixed method approach was used (Robson, 2011). Information about farmers' evaluation of soil fertility was collected using individual interviews and a standardised questionnaire using closed and open-ended questions to collect both qualitative and quantitative data (Robson, 2011). The questionnaire for interview was constructed with the questions to collect the data about the indicators of soil fertility, the location and scale of the best and the worst soil in farmers' fields. Although farmers are managers of different farms and recognize small difference even in the same field, this research focused on soils that farmers evaluated as the best or worst fertility location to avoid over-complexity. Approximately 50% of the total number of households in each village was randomly sampled and the person who decided management of their fields (usually the household head or wife) was purposively selected as the interviewee inside each household. The total number of sampled farmers was 60 (30 in each village). Focus group discussions supplemented understanding of the historical narratives by showing how historical events affected the construction of indigenous soil fertility evaluation. Purposive sampling (Tongco, 2007) for participants was used as elder farmers (four farmers per a village, aged between 53 and 83 years old, who knew about historical changes in soil and agriculture) were able to discuss the historical context. The questions for group discussion included previous soil condition and farmers' lifestyle, and the effects of social and environmental change on soil fertility. A trained local translator was used for discussion between English and KiKamba, although some farmers spoke English. All written and audio data were recorded with consent from participants.

4.2.3. Soil sampling and laboratory analysis

Soil samples were collected in August 2016 from the best and the worst fertile place in fields, as identified by each farmer. The sampling occurred just after harvest and the last short rains in fields that had not yet been prepared for next growing season. This was considered good timing for evaluating baseline soil nutrient status with minimal impact from additional inputs. Surface (10cm) soil samples were taken from 10 points within each field and bulked to make single composite samples of 500g. The total number of soil samples was 116, 59 from the best fertile locations and 57 from the worst fertile places. This was because four farmers had just one farm and one of them evaluated their field as not fertile only while another evaluated their fields as fertile only.

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

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

WHC (%) = (mass of drained soil - mass of oven dried soil)/ mass of oven dried soil × 100.

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

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

4.2.4. Data analysis

Qualitative interview data was treated first by coding (Coffey and Atkinson, 1996) to analyse the frequency of soil names, soil characteristics, location and scale of the best and worst soil in farmers' fields. Additionally, simple descriptive statistics were used. Narratives from the interviews and focus groups were organised to reveal insights into these identified patterns. Results from the soil physicochemical analysis were compared to farmers' evaluations to reveal patterns and relationships between the villages. Statistical analysis of quantitative data was performed using Minitab 17. Pearson's chi-squared test was used to assess differences between 1) villages and farmer-selected locations of the best and worst fertility soil, 2) farmers' soil fertility evaluation and local soil name, 3) villages and soil texture and 4) villages and locally determined soil colour classifications. A General Linear Model (GLM) was used to explore differences between the physicochemical data and farmers' evaluations of soil fertility. A multiple comparison approach was used to compare relationships between soil physiochemical data and soil texture/locally determined colour classifications ($P < 0,05$). The results of TOC, TN, NN, AP, K, Na, CEC and EC took the Log of the data first and then fitted the GLM to the logged data to consider normality of residuals. A detailed description of the study location and study method can be found in Chapter 3.

4.3. Results

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

4.3.1. Farmer knowledge: key soil properties used in farmers' evaluation of soil fertility

The characteristics of soils of the best and worst fertile places were described by farmers in response to an open question (Figure 4-1). The percentage mean the share of respondents who mentioned the characteristics at least ones. Texture was the primary soil property used by farmers to evaluate both best and worst fertility. Colour was used to identify best fertility. There were other properties used by farmers, but these were less commonly used across the whole group. In total, 13 soil properties were identified as indicators for both best and worst soil fertility: texture, colour, workability, plant performance, water, stoniness, weeds, feeling, fertilizer, location, root and sub-soil. Temperature was used only as an indicator for worst soil fertility.

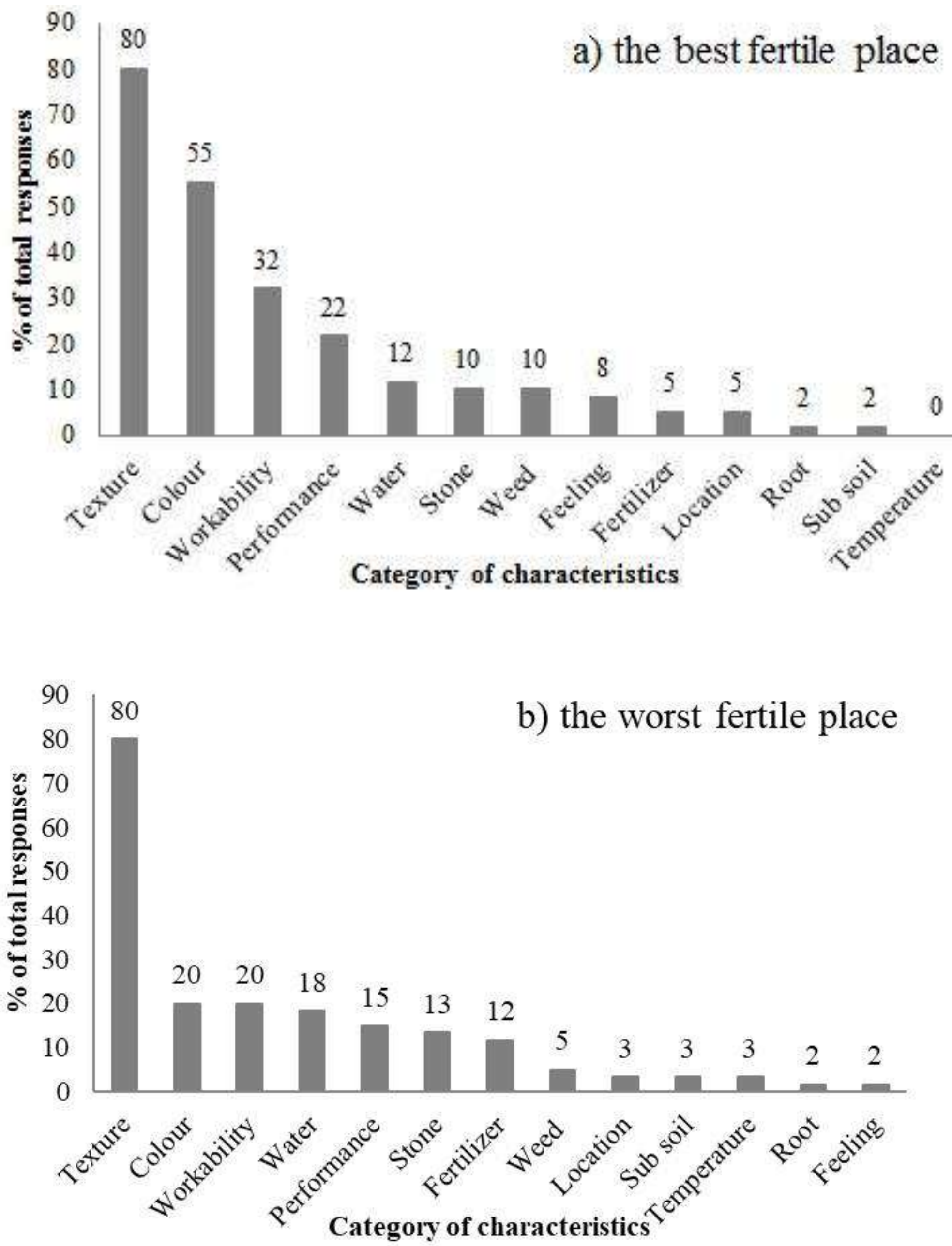


Figure 4-1 Farmer indicators of soil fertility (a) indicators of best soil fertility place (n=59), (b) indicators of worst soil fertility place (n=57)

When describing best soil fertility (n=59, Figure 4-1a), farmers relied on fine soil texture (80%) and a black or red colour (55%) to describe the soil. Of the farmers, 27% recognized a difference in soil workability (e.g. the need for only moderate wetness to plough easily whereas in very wet conditions soils can be difficult), 22% referred to good plant performance and linked this to water availability (12%, "*Even in dry season, I felt moisture when I dig the place*" V2_6). Other factors mentioned included the absence of stones (13%), soils with a 'good feeling' (8%), more 'fine' weeds (5%, "*It is easy to pull* *weeds out by hand*" V1_5), past use of fertilizer (5%, "*I added a lot of manure in the place in the past, so now here is fertile*" V1-4), location near the house where there are often more inputs (5%), longer roots of plants (2%), and an observed different type of sub-soil (2%). When classifying the worst soil fertility (n=57, Figure 4-1b), texture was again the main factor (80%) but defined as coarse. A light soil colour (20%) was the second factor but reflected a smaller response in comparison to texture. Other indicators mentioned included difficult 'workability' of the soil (20%, "*The soil is too hard when it is dry so I need rain for plough.*" V1_16), less water availability (18%, "*The soil is dry faster due to drain faster.*" V1_29), and poor crop performance (15%), more stones (13%), no fertilizer use (12%), many weeds (5%), far from the house (3%), a different type of sub-soils (3%, "*When dig the soil deeper, I found the red soil with shiny particles*" V2_6), hotness (3%, "*When I dig the soil in dry season for preparation, the sandy soil is too hot*" V2_15), small roots (2%) and a 'bad feeling' for soil (2%).

4.3.2. Farmer knowledge: Role of farm scale and location

The scale of evaluation of soil fertility was very detailed within each farm. Farmers clearly understood differences in soil fertility. Out of the 60 interviewees, 88% were able to designate portions of their farm as the best or worst place ("*The portion near tree is better than other because of supply of leaves.*" V1_26, "*My home field is located on slope so the bottom of slope is more fertile than up due to washed soil from up accumulate there.*" V2_13, "*There is a portion of natural black soil in the centre of my field and there is more fertile.*" V2_22) while 12% evaluated their whole farm as having the same soil fertility ("*The soil is same because my current field is quite small after dividing other for my children.*" V1_24).

Of the total sample, 46% selected the area around their house and inside the home-field as the primary location for best soil fertility. This kitchen garden or *Mũthĩo* (in KiKamba phonetic transcription, Whiteley & Muli 1962) is where livestock are often confined, so manure and composts accumulate (Woomer et al., 1998). The next best soil fertility area identified by the total sample was near to a river (20%). Comparison between the two villages reveals are differences in response. Village 1 reported that areas within their kitchen gardens were better (67%) than their away-fields (20%). In Village 2, farmers evaluated their away-fields as more fertile than kitchen gardens (24%) (the difference between villages was significant, Pearson's chi-squared test P=0.006**). The influence of the river was important to soil fertility in Village 2 (38%). There were also differences in the number of fields managed by farmers between the villages; Householders with more than two fields being managed were 33% in Village 1 and 77% in Village 2. This difference affected their selection of the best soil fertility locations on their farm overall, as farmers in Village 2 had more opportunity to use the good soils near the river.

4.3.3. Farmer knowledge: Local terminology for soil fertility evaluation

Farmers judged the fertility of soils by the healthiness of the crops grown. This connection was reflected in the articulation of soil fertility, with healthy (fertile) and non-healthy (unfertile) terminology used. Farmers perceived a connection between the healthiness of soils, plants and people (e.g. between good soils and production, food security and nutrition), and articulated this relationship using visual terms or outcomes (e.g. 'an overweight person would have fertile soil and more to eat'). In KiKamba, soil is called *Mũthanga* and the word for fertile is *Mũnou* so soil with good fertility is described as *Mũthanga Mũnou*. The word *Mũmosu* is used to describe a lack of fertility, and therefore poor soil fertility is *Mũthanga Mũmosu*. Interestingly, *Mũnou* and *Mũmosu* were also terms used for expressing human healthiness. A human being is called *Mũndũ* in KiKamba, with *Mũndũ Mũnou* used to refer to an overweight person, and often used to convey being healthy or having contentment. In contrast, *Mũndũ Mũmosu* is used to refer to an unhealthy thinness or something lacking in the human body. Technical or science-based crop performance indicators were not used by farmers as the terminology to describe soil fertility at all (Figure 4-1) as farmers considered it necessary to reflect initially on the characteristics of *Mũthanga Mũnou* (or *Mũmosu*) and the collective healthiness of the soil and the crops.

Table 4-1 presents farmers' soil classification terms and how these relate to their designations of best and worst soil fertility on their farms. Farmers relied on 11 classifications, eight locally-defined terms and three defined in the English language. The eight locally-defined terms were divided into three groups: feature of soil; fertility classification; and formation type. There were five categories based on physical soil properties, including texture and colour, sandy soil (locally known as *Nthangathĩ*), black soil (*Mwiũ*), red soil (*Mũtune*), stony soil (*Kĩvuthĩ*) and black-clay soil found near rivers (*Ĩlimba*). Most answers were organised into these physical soil categories (91%) and KiKamba terminology was used for the majority of soil classification labels by farmers in Kitui. Although there were some synonyms and a few instances of mixes of category, it was still possible to consistently identify a dominant soil type when interviewing with farmers. For example, in the category of *Mũtune* (red soil), there were two synonyms, *Kĩtune* and *Ũtune,* and a mix with *Ĩlimba,* i.e. red soil with some black clay). Terminology for soil fertility could also refer to it as good (*Mũnou*) or bad (*Yalata*). There was just one category that reflected soil formation characteristics, which was a type of sedimentary soil called *Kĩvumbu* (the other meaning of *Kĩvumbu* is clay soil found in termite mounds, personal communication with a local scientist). In addition to these local terms, three English terms were used to denote loam, clay and white soil.

Table 4-1 Local soil classifications, with associated soil fertility and texture terminology (n=116, source: structured interview data 2016)

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

There was a clear relationship between the terminology of farmers' soil classification and their evaluation of soil fertility (Table 4-1). Of the total, *Mũnou* (1 in 1), *Kĩvumbu* (1 in 1), *Ĩlimba* (12 in 12), *Mwiũ* (23 in 24), and *Mũtune* (13 in 19) were categories used to evaluate fertile soil. In contrast, course soil texture *Nthangathĩ* (29 in 34), *Kĩvuthĩ* (16 in 16) and *Yalata* (4 in 4) were used to evaluate poor fertility soils. The relationship between local soil classification and farmers' fertility evaluation was significant (Pearson's chi-squared test P=0.000***, with local soils including more than 10 soil samples used in the test), indicating that farmers were consistent in their use of local soil terminology and association of these terms with best and worst soils. In addition, there was a difference in occurrence of locally perceived soil types between the two study villages. *Mwiũ* and *Mũtune* (11 and 11 in 30) were dominant in Village 1 and *Mwiũ* and *Ĩlimba* (12 and 11 in 29) were dominant in Village 2 to describe good soil fertility. *Nthangathĩ* was dominant as the worst soil fertility in both villages, although *Kĩvuthĩ* was additionally recognized in Village 2 as a worst soil fertility location. Notably, English terminology was used only in Village 1.

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

Texture associated with each local soil classification was compared to scientific analysis of soil samples. The results of texture analysis made by a hand test were aggregated into three categories: clayey refers to clay dominated (more than 35% clay), including clay, sandy clay and clay loam; loamy describes moderately sandy, including sandy clay loam and sandy loam; and sandy, which is sand dominated (more than 75% sand), including loamy sand and sand. Clayey to loamy texture soil types were mainly classified from the best soil fertility locations, while coarse (sandy or stony) soils were classified from the worst soil fertility locations. *Kivuchi* and *Yalata* were classified as clayey to loamy texture using a hand test and those with significant stone content removed by sieving were classified as stony or coarse soils (Table 4-1).

Soil samples were compared to a Munsell colour chart and named using the guide at https://logiteasy.com/free-tools/munsell-calculator.php (Table 4-2). Soil colour was not significantly different across the soil classification by the chart. In total 11 soil colours were recognized but these were dominated by just three colour names (dark brown, dark yellowish brown and brown). *Ĩlimba* (6 in 12), *Mwiũ* (14 in 24), *Nthangathĩ* (16 in 34) and *Kĩvuthĩ* (7 in 16) were classified in dark brown, while *Mũtune* related to brown. The limited difference between soil colour name and local soil classification can be attributed to the naming system of the Munsell colour chart. The colour range that categorises dark brown, dark yellowish brown, brown and strong brown is wider than for other colours.

Table 4-2 Soil colour by local soil classification organised by the Munsell colour chart (wet conditions) (n=116)

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

Table 4-3 Physicochemical parameters of each local soil classification (n=116)

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, + Nthangathĩ)	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 also differed between local soil types, which were classified into the best and worst soil fertility locations (Table 4-3). 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* showed higher TN. However, for other soils TOC and TN were deficient. This critical level indicated a 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 could be implied that the soil was low in organic matter.

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

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

Further analysis was carried out to examine the relationship between farmers' indigenous knowledge and technical knowledge obtained through the above physicochemical analysis with respect to the two key soil properties farmers use to assess fertility: texture and colour (Figure 4-1).

The difference in soil texture could be shown to be reflected in the values found in the physicochemical analysis (Table 4-4a). First, the frequency of appearance of the three texture classes used for best and worst fertility places was significantly different. For example, for the whole sample, the best fertility soil had a finer texture than the worst fertility soil (P=0.002**). The village location further affected the soil texture, with significantly more clayey soils in Village 1 than Village 2 (P=0.015*). This reflected the red clay soil (*Mũtune*) sampled in Village 1. Additional exploration of the relationship between texture and physicochemical properties identified as significantly different between the best and worst fertility soil and the location was performed (Table 4-4b). The GLM models included soil fertility evaluation and location as factors and it was found that there was significant difference between all properties identified and the texture categories. Multiple comparisons on the 95% confidence interval showed significant differences in pH, TOC and WHC among clayey, loamy and sandy textures. The respective values were higher for finer soils. The average values of AP, K and EC were higher for clayey, loamy and sandy soils respectively, but the difference was not significant.

Table 4-4 Relationships between soil texture and (a) soil fertility evaluation or village location (Pearson's 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 fertility evaluation	best	24	30	5	0.002**
	worst	18	19	20	
Village location	1	28	22	8	0.015*
	2	14	27	17	
(b)		Soil texture			P value
		Clayey (n=42)	Loamy (n=49)	Sandy (n=25)	
pH		6.48a	6.43a	6.03b	P<0.05
TOC g kg-1		1.21a	0.99b	0.97b	
AP mg kg-1		76.0a	76.1a	64.20a	
K cmol kg-1		1.23a	1.09a	1.03a	
EC ds/m		0.09a	0.08a	0.07a	
WHC gH2O gdry soil-1		50.6a	39.4b	35.0c	

*P <0.05, **P <0.01

Although Table 4-2 did not show a clear difference for colour with local soil classifications, farmers rely on colour as an indicator for their evaluation of soil fertility. Therefore, a further correlation between colours from farmers' classification and the physicochemical data was performed (Table 4-5). From the 116 soil samples, 105 which could be categorized into the five major local soil types were selected and ordered into three categories: Blackish (n=36) including *Ĩlimba* and *Mwiũ*, Reddish (n=19) including *Mũtune* and No colour mentioned (n=50) including *Nthangathĩ* and *Kĩvuthĩ*. There was a significant difference of appearance for soil of each colour in the soil fertility evaluation (P=0.000***) and between villages (P=0.017*) using a chi-squared test (Table 4-5a). Blackish and Reddish soils were mainly classified as best soil fertility locations and no colour mentioned soils were found in the areas with worst soil fertility. There was more Blackish soil and less Reddish soil in Village 2 than Village 1. This reflected the sample of *Mũtune* from Village 1 and *Ĩlimba* from Village 2. Multiple comparisons on the 95% confidence interval showed a significant difference for pH, TOC, AP, EC and WHC among the Blackish, Reddish and No Colour soils (Table 4-5b). The average value of K was higher for Blackish, Reddish and No Colour respectively but the difference was not significant. The pH, TOC and WHC could be associated with differences in both local colour and texture; AP and EC were associated with local colour only.

Table 4-5 Relationship between local soil colour and (a) soil fertility evaluation or village (Pearson's chi-squared test) (b) and results of the physicochemical analysis (multiple comparison) (n=105)

(a)		Colour of major local soil types			P value
		Blackish (n=36)	Reddish (n=19)	No Colour (n=50)	
Soil fertility evaluation	best	35	13	5	0.000***
	worst	1	6	45	
Village	1	12	14	23	0.017*
	2	24	5	27	
(b)		Colour of major local soil types			P value
		Blackish (n=36)	Reddish (n=19)	No Colour (n=50)	
pH		6.57a	6.62a	6.10b	P<0.05
TOC g kg-1		1.05ab	1.19a	0.97b	
AP mg kg-1		101a	71ab	54b	
K cmol kg-1		1.24a	1.09a	1.07a	
EC ds/m		0.10a	0.07ab	0.07b	
WHC % gH2O gdry soil-1		47.8a	44.1a	37.8b	

*P <0.05, ***P < 0.001

4.3.6. Soil evaluation and historical narratives

Farmers' narratives about their evaluation of soil fertility, classification and connection with social change were collected through focus group discussions with elder people and storytelling during individual interviews. In particular, farmers in both villages noted a change in local soil conditions with soil degradation over time: in comparison with their historical recollections, soil fertility had decreased and cultivation was more challenging: *"For the past generation of farmers, there was a lot of humus, fertile soil…if working this humus, it reached until the knee. The soil was covered by humus so we couldn't see the soil type"* (Village 1); *"All the soils were black (Mwiũ) so you didn't need to recognize 'soil type' in the past. The head of the family always decides the best place by checking if the soil is loose, if it can be dug by hand and if there is a lot of humus… but nowadays after two or three rain seasons in cultivation, the soil fertility is a problem and the crops do not grow well. When you then dig the soil, it will make a noise [from the stones] …and this means is not a good field. In the past, the family could shift to other places as the land belonged to no one that time"* (Village 2). However, the introduction of regulation in land ownership impacted traditional land use systems and ultimately the quality of the soil, as "*after the surveyors came, they introduced new government rules and people were settled in the same place"* (Village 1), limiting farmers' ability to practise extensive agriculture or even long-term fallow rotation.

With many farmers having a limited capacity to practise intensive farming and maintain soil fertility, there are challenges for current soil fertility: *"The rain washes away the humus and top soils...after humus rich surface soil loss, other soils (Mũtune, Nthangathĩ, Kĩvuthĩ) now appear"* (Village 2); *"The population in the village has increased and people here often cut the trees to make charcoal to sell, so the forest is reduced"* (Village 1); *"the soil colour was originally black but now it is a bit pale and this means the soil has become old. My crop production has been reduced"* (Village 2). Individual storytelling revealed that some farmers actively were attempting to practice low-cost improvement techniques through organic manures, soil and water conservation or mulching: *"when I moved to the place and built the new house, the soil was poor… but I collected leaves and humus from the forest and spread it over the field and it has made the soils more fertile"* (Village 1). Gender differences were not explored throughout this study.

4.4. Discussion

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

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

This simple approach to soil classification and evaluation may reflect the relatively short history of agriculture in this area. According to farmers' narratives of agricultural development in the region, soil knowledge and management has been shaped by social change. Traditionally farmers have evaluated the soil humus and texture to decide on the best locations for shifting cultivation since the 17^{th} Century. These two indicators were also reported as common in indigenous soil classification in other areas (Barrera-Bassols and Zinck, 2003). However, these evaluations may not have been relied upon as much in the past because there was plentiful fertile land before 19^{th} century. Increased settlement and the implementation of a land ownership system in the 1970's (Ikeno, 1989) restricted local farmers' traditional systems, with losses in the humus rich surface soil and appearance other soil types with less organic matter seen to the surface from subsoil. It is this reworked soil that is captured in the current local soil classification, but which may have been used for less than half a century. While nearby Machakos, another Kamba settlement, suffered degradation of its agricultural land up to the 1930s, a landownership system and introduction of terraces led to conservation improvements (Karanja et al 2017, Tiffen et al. 1994). The story of agricultural extension in Kitui is, however, more recent, and there has been no large-scale land conservation project like that in Machakos (Karanja et al 2017, Ikeno 1989, personal communication with extension officers in Kitui). Investment in terracing of fields has been in Kitui but many have been damaged by high intensity rain. The growing population has placed pressure on forest resources, reduced farm sizes through traditional subdivision of land holdings for each generation, increased local food demand and required a more intensive farming approach (Ikeno, 1989). The narratives and soil knowledge reported by farmers in the study primarily reflect their experience after this period of social change.

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

There were differences in how farmers recognized soils between the two study villages. For example, while farmers in Village 1 classified some soils on their farm in English, this was not the case in Village 2. This reflected the availability of agricultural information in the school and access to an agricultural extension worker in Village 1. There was difficulty in communication between extension workers and farmers in Village 2, which was in a comparatively more remote area (Anderson, 2006). The positive effects of extension services in providing farmers with soil science-based knowledge are well known (Muyanga and Jayne, 2006). Extension staffs had informed farmers that *"Sandy loam soil was the best for cultivation of maize"* (personal communication with an extension officer in Kitui), although a local term which meant "loam" did not exist in this area and farmers understood a loam texture as a mixture of clay and sand. Another difference between the two villages was the selection of the location determined as the best or worst for soil fertility. This can be attributed to a difference in availability of land. As illustrated by the number of farmers who have more than two fields (Village 2 is higher), land is more difficult to acquire, buy or rent in Village 1 because of a higher population density in the area since it is nearer to the town (The County Government of Kitui, 2014). Moreover, the elevation of Village 1 is similar but slightly higher than Village 2 and the availability of black clay soil near the river, made by alluvial deposits, is less than in Village 2. Farmers in Village 1 have limited opportunities to use away-fields and consider differences in soil fertility on their owned fields as an effect resulting from better inputs and management than natural variation in soil type. As mentioned above, application of organic matter from the house makes the soil colour darker and increases the proportion of black soils in the local classification. While both intensification and natural diversity can lead to differences in texture and colour, the core concepts used by farmers for their evaluation of soil in both locations was the same. Given the national interest in supporting intensification of the use of these soils, understanding the underlying epistemological framings for management decisions by farmers are vital (Bozzola et al., 2016; Verkaart et al., 2017).

Furthermore, there was consistency in aspects of the core concepts (Figure 2-2) used to evaluate soil fertility by scientists using soil science methods and farmers' indigenous knowledge in Kitui. The results of the physicochemical analysis from locations identified by farmers as the best soil fertility areas were significantly better than those identified as the worst, and in particular this reflected a focus on organic matter content, pH, AP, K and WFC. This finding supports the argument by Murage et al. (2000) and Mairura et al. (2007) that Kenyan farmers' soil evaluation is highly consistent with soil science evaluations. Texture is the basis by which to understand soil structure and it is related to aeration, space for plant roots and moisture, which directly affect crop performance (Brady and Weil, 2016). Thus soil texture can indicate the potential level of nutrient and water holding capacity of a soil (Brady and Weil, 2016), which was identified to be significantly different in pH, TOC and WHC (Table 4-4) between the soils with different texture. Coarse soils were determined by farmers to be problematic and often identified as the worst soil fertility location on their farm. This reflected their understanding of soil process, such as rapid drainage of water through the coarse soil particles, a problem in a region that experiences erratic rains and frequent drought spells because it leads to crop loss. Even if these are low-cost water conservation techniques, they can be labour intensive (Oguge and Oremo, 2018). The coarse particles are due to components from the metamorphic bedrock (Bishop et al., 1999), especially silicate minerals such as microcline and oligoclase (Mine and Geological Department Kenya colony North-West Quadrant, 1954) which create sand. These sandy soils are considered problematic for farming locally and are called *Yalata* in KiKamba. Other studies have described coarse textured soils to be perceived as problematic by farmers (e.g. the *Tanah Tahinagan* soils in Indonesia) (Kamidohzono et al. 2002).

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

Summarizing the achievements of this study as adapted in Figure 2-2 (Barrios et al., 2006), Kitui farmers and soil science share the use of soil texture and colour as core concepts for soil fertility evaluation. The information from farmers' observation and evaluation of field management and the history of social and environmental changes is lacking in soil science. On the other hand, the relationships between soil properties and soil process is less well understood by farmers, and the role of organic matter in soil is not mentioned by farmers, although it is a dominant topic in soil scientists' consideration of water retention (Brady and Weil, 2016; see chapter 6). Water availability is a particularly challenging factor for agricultural production in Kitui and most farmers rely on rainfed supply, exposing them to the risk of drought (Ikeno, 1989). Instead of holistic, (Barrera-Bassols and Zinck, 2003), Kitui farmers currently use qualitative indicators more readily than quantitative measures**.** Using local terminology, soil colour and texture as an entry point of communication with farmers and sharing of information about soil processes (or 'know-why') about water and nutrient retention, together with farmers' empirical knowledge, could help to provide a genuine two-way form of communication and social learning (Ingram, 2008; Leeuwis and Aarts, 2011; Lie and Servaes, 2015). The creation of local tailor-made soil assessment systems with local terminology using hybrid knowledge with collaboration of farmers, soil scientist and extension officers can integrate precise spatial information from farmers and the mechanisms of soil function from soil science, which would then provide the potential to support effective site-specific precision agriculture systems (Osbahr and Allan, 2003) and increase the sustainability and adaptability of soil management technology.

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

4.5. Conclusion

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

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

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 improve understanding of farmers' conceptualisation of soil fertility. This study visualizes farmers' perceptions of soil fertility as mental models, in order to explore the expansion of their soil knowledge and the extent of their comprehension of the relationship between soil properties that are seen and measured and soil processes that underpin how soils function in terms of nutrient cycling and resilience to flood and drought, for instance. 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 analyse 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. Farmers placed emphasis on contextual information related to location. 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. Farmers understood the visual features of soils (e.g. texture and colour), so using visual materials about soil, including videos, could improve communication with them in future. 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 farmer knowledge.

5.1. 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). 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 recognise the value of indigenous knowledge and the experience of farmers themselves (Barrera-Bassols and Zinck, 2003; Ingram et al., 2010). If knowledge exchange is indeed essential for sustainable development (Munyua and Stilwell, 2013; Ramisch, 2014), learning and integrating farmers' knowledge fills the gap between science and farmers' empirical knowledge (Barrios et al., 2006; Reed et al., 2014; Guzman et al., 2018). 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. (Oldeman, 1992; Berazneva et al., 2018).

To achieve this, multi-disciplinary insights from the field of Ethnopedology, which document and understand local approaches to soil perception, classification, appraisal, use and management (Barrera-Bassols and Zinck, 2003), should be better recognised by the soil science community (e.g. Murage et al., 2000; Osbahr and Allan, 2003; Mairura et al., 2007; Rushemuka et al., 2014; Pincus et al., 2018). Publication of Ethnopedological research in more science focused journals like *Soil Use and Management* and *Geoderma* is one way to improve cross-disciplinary communication (e.g. Barrera-Bassols and Zinck, 2003; Prager and Curfs, 2016). Ethnopedological studies have revealed that farmers' knowledge systems are holistic, interconnected and reliant on hybrid forms of knowledge, rather than being focused on specific science-oriented reductionist dimensions, such as crop production, or soil properties and process (Fry, 2001; Barrera-Bassols and Zinck, 2003). However, in spite of advances in ethnopedological and other research on farmers' perception of soil fertility, quality and management (e.g. Dawoe et al., 2012; Adimassu et al., 2013; Friedrichsen et al., 2018), it remains unclear how farmers understand soil fertility and how to conceptualize the framing of soil properties and processes.

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; Wagner, 2007). One type of mental model is the 'semantic web' (Novak and Growin 1984), where a semantic web diagram shows 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). Visualisations through diagram-based representations of mental models provide a simple and understandable tool to identify and overcome the limitations of stakeholders' knowledge (Morgan et al., 2002).

This study aims to respond to further understanding of farmers' soil knowledge by creation of mental models of soil fertility, exploring their understanding of the relationship between soil properties and processes that soil scientists also use. The mental model approach has not yet been applied to Kenyan farmers' soil knowledge, and it can offer useful insights regarding farmer understanding of soil fertility that other approaches may not yet have revealed. 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. It can facilitate the consideration of soil fertility in a more holistic way by creating aggregated mental models of sampled farmers, allowing reflection on overall conceptualisations of soil fertility and also revealing knowledge gaps among farmers. Although differences between scientists and farmers are well reported, differences in conceptualisations of soil fertility between individual farmers are less well documented (Ingram et al., 2010; Ramisch, 2014). The objectives of this study are to: (1) construct 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) examine differences in knowledge about soil fertility among farmers and between villages. By reflecting these insights, how understanding farmers' metal models of soil fertility may help to enhance communication between farmers and other stakeholders, such as soil scientists is also discussed.

5.2. Methods

5.2.1. Location of data collection

Kitui County, Kenya, was selected for this study because it has low soil fertility and limited precipitation which cause low agricultural productivity (County Government of Kitui, 2013). The area has a semi-arid climate with a mean annual temperature between 14℃ and 34℃. There are two rainy seasons, a 'long' season from October to December and a 'short' season between March to May, according to local perceptions, which is the opposite pattern to that recorded in the governmental publication (County Government of Kitui, 2014). The total annual rainfall range is between 250mm and 1050mm (County Government of Kitui, 2013). The majority (87.3%) rely on agriculture to earn a livelihood (County Government of Kitui, 2013). Small scale farmers grow maize, legumes, green gram, cowpeas and pigeon peas on small farms (averaging 2.5ha), and depend on the rains for cultivation (County Government of Kitui, 2013). 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 (Ralpph et al., 2006; County Government of Kitui, 2013). In Kitui, two villages (Kavuti: Village 1 and Kitambasyee: Village 2) were selected by purposive sampling (Tongco, 2007) with four criteria: (a) location in the same soil type (Um19), based on the national soil map, and in the same Agro-Ecological Zone (AEZ) (marginal cotton zone (vs/s+s/vs)); (b) the majority of villagers engaged in small-scale farming; (c) different distances from Kitui town centre and different frequency of communication with extension workers (that in the closest being higher than in the more remote location); (d) no active NGO activity or agricultural extension project. The reason for choosing these criteria was to allow the study to evaluate the effect of the difference of location on soil knowledge. Um19 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 communication from Agricultural Extension officials - 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, although due to limited transport it could take more than 2 h to walk, and there was limited communication with agricultural extension officials.

5.2.2. Collecting data on farmers' soil knowledge

In the two sampled villages, Causal diagrams (Galpin et al. 2000) were used for the data collection. 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 wife) was invited to be the interviewee. 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. The same questions were repeated for fields on their farm with 'the worst fertility'. Of the 59 farmers, 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 worst 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 (see Chapter 4). All communications were in English and the local language, KiKamba; a trained local translator acted as interpreter. All data collection in Kenya was done under a research permit from the National Commission for Science, Technology & Innovation (NACASTI). Consent from participants was taken before the 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 dominated answer was selected as the representative concepts. KH coder- word-association software (http://khc.sourceforge.net/en/) which has been used in the analysis of public opinion, mainly in Japan (Maeda, 2015; Tsukada and Morita, 2018) - was used for counting the share of respondents in total and per each village and checking the connection between the concepts. The links between the representative concept were connected with the manually selected relationship terms, according to the farmers' narrative data. The same process was repeated for the creation of the sematic web of low fertility soil. The category with the share of respondents for fertile soil was shown as an example of qualitative data coding in Appendix 9.

The prioritized focus of this study is to reveal the fundamental understanding of soil fertility by farmers in this community and while there were some differences in farmers between villages and the rates of some answers were very low. Therefore, I felt aggregate between two villages was appropriate given similarity in knowledge. Farm management in this area is changed based on farmers' soil fertility evaluation (see Chapter 4 and 7) and the comparison of the mental models for fertile and low fertility soils highlight the different perception being the base of different soil management. To reveal the different perception on different soil fertility, the participatory method asked farmers to talk about most fertile fields and least fertile fields and the same questions were asked to farmers in the different villages. By showing the share of respondents of each concept in the mental models, the knowledge gaps happen among farmers and between villages are made visible.

5.3. 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 other for 'low fertility'. The percentages in this result section indicate the share of respondents who mentioned the concept at least once. These answers were categorized as the main (≧10%) and minor (<10%) concepts in the aggregated mental models in this study to reveal the familiar and unfamiliar concepts among farmers.

5.3.1. Farmers' mental model of fertile soil

Based on analysis of the 58 answers within the sample, farmers reported that their main rationale for planting cash crops (e.g. hybrid maize, beans and vegetables) in their most fertile soil location was because these crops needed more nutrients than others. All farmers' reasons for planting these specific cash crops were because of 'good harvests. Therefore, yield or harvest is the primary measure of good soil fertility. Three thematic areas emerged to characterise farmers' perceptions of explaining or identifying areas with good soil fertility: soil management, soil property and specific location (Figure 5-1). The different focuses of the two village were also revealed (Table 5-1).

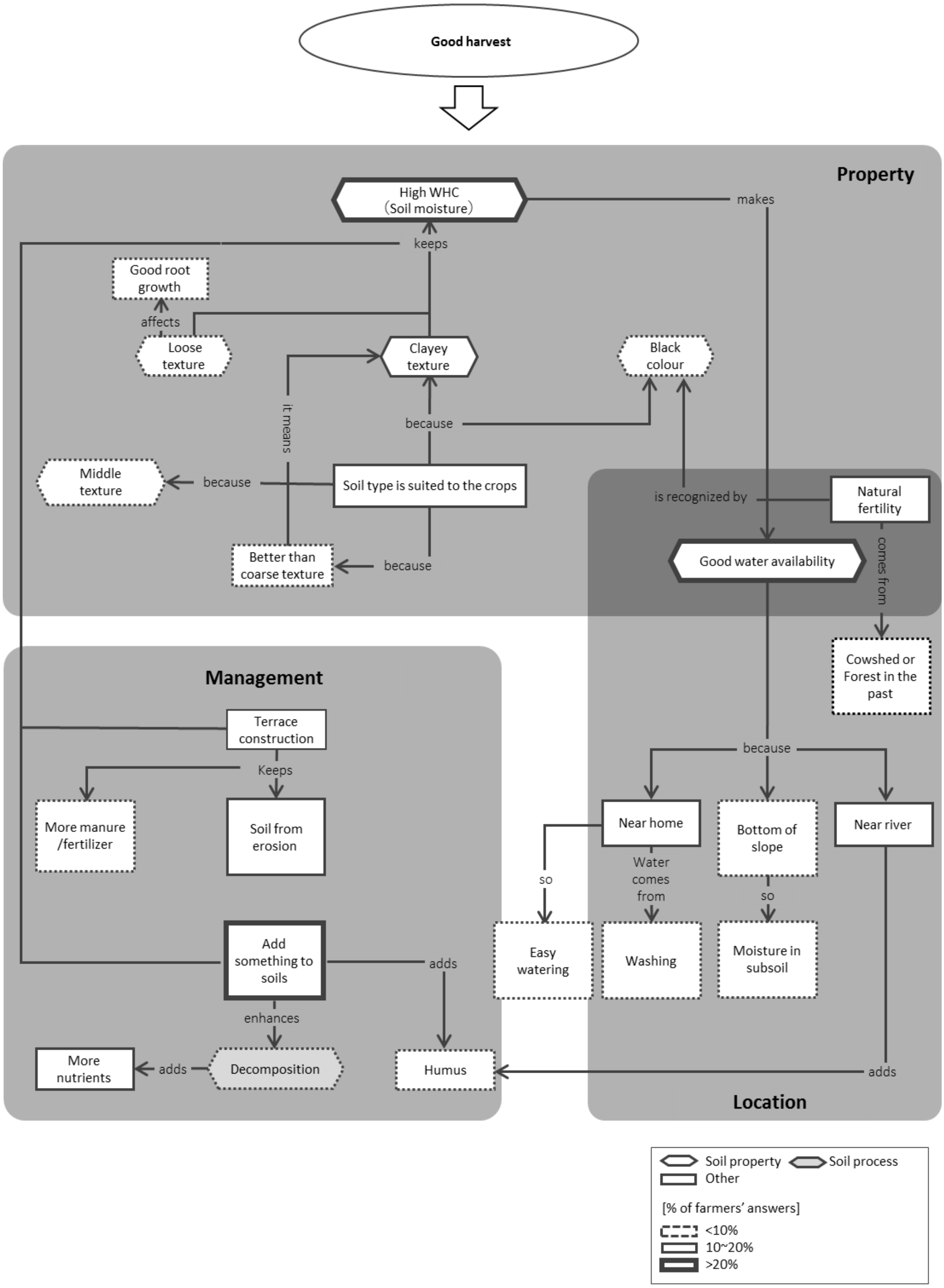


Figure 5-1 Mental model of fertile soil by Kitui farmers (n=58, source: structured interview with Kitui farmers, August-September 2016)

Table 5-1 Share of key concepts per village for fertile soil (n=58, source: structured interview with Kitui farmers, August-September 2016)

Category	Concept	Village		Total (%, n=58)
		Village 1 (%, n=29)	Village 2 (%, n=29)	
Property	High WHC	14	34	24
	Good water availability	10	45	28
	Clayey texture	17	31	24
	Loose texture	0	14	7
	Middle texture	7	3	5
	Black colour	3	7	5
Process	Decomposition	3	0	2
Management	Add something to soil	69	21	45
	Terrace construction	10	17	14
	Humus	0	7	3
Location	Near river	0	38	19
	Near home	14	14	14
	Bottom of slope	0	14	7

Main concepts (≧10% of farmers)

The aggregated model shows large variation in farmer knowledge, with only >20% farmers agreeing on three key properties: water holding capacity (WHC) (24%), good water availability (28%), Clayey texture (24%), and a management concept: adding something to the soil (45%).

Soil management was related to crop performance. The term 'naturally fertile' (14%) was used by farmers to describe a location where crops grew well without additional inputs. 45% of the sampled farmers perceived the application of soil amendments, such as fertilizer, animal manure, plant residue and domestic organic waste, as a way to improve soil fertility. Of the sampled farmers, 14% felt this was important because of the added nutrients essential for plant growth. 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.

Water emerged as an important theme when the farmers' mental model of fertile soil was associated with soil's physical properties, particularly texture. 24% of the sampled farmers specifically mentioned WHC (or 'soil moisture') as a sign of fertility. Clay textured soils (24%) were associated with good water holding capacity. 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%), which was also related to the location of soils. The specific geographical location and topography of a plot was understood to affect water availability. Within the study area, fields around the homestead (14%) or close to rivers (19%) were considered the locations where the wettest and therefore most fertile soil was normally found.

Minor concepts (<10% of farmers)

In the management discussion, only one farmer (2%) was able to describe the process of decomposition of organic matter in the soil and the supply of nutrients from the newly opened field. The role of terraces in retaining manure and chemical fertilizer was also rarely mentioned. One farmer's answer acknowledged the role of applications of organic matter in increasing WHC.

During the discussion of soil properties, 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. 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 colour (5%).

As another fertile location, the bottom of slopes (7%) was also mentioned with moisture in subsoil (7%). 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%). Natural fertility 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 mould (5%).

Table 5-1 shows the different share of key concepts, especially soil properties and processes, in the two villages. The farmers who lived in Village 2 gave more answers about soil physical processes (high WHC, good water availability, clayey and loose texture and black colour) than those in Village 1. The answers on the topographical features (near rivers and at the bottom of slopes), the importance of terrace construction and the existence of humus were also dominated by Village 2 farmers. In contrast, Village 1 farmers were intensely focused on the importance of soil amendments and organic and chemical fertilizer (69%). The only farmer who mentioned the soil process of decomposition was in Village 1. The importance of terrace construction and advantage of location near home for better soil fertility was recognized equally in both villages.

5.3.2. Farmers' mental model of low fertility soil

The farmers' mental model of low fertility soil (Figure 5-2, n=56) started from the good productivity of specific crops that were tolerant of drought and a limited supply of nutrients, including cowpeas, pigeon peas, green gram, cassava and some maize varieties. The model reveals the same thematic areas as for fertile soils: soil management, soil properties and specific location. However, farmers emphasised the soil properties when describing poor quality soils. The difference between the villages followed a similar trend to their respective views on fertile soil (Table 5-2).

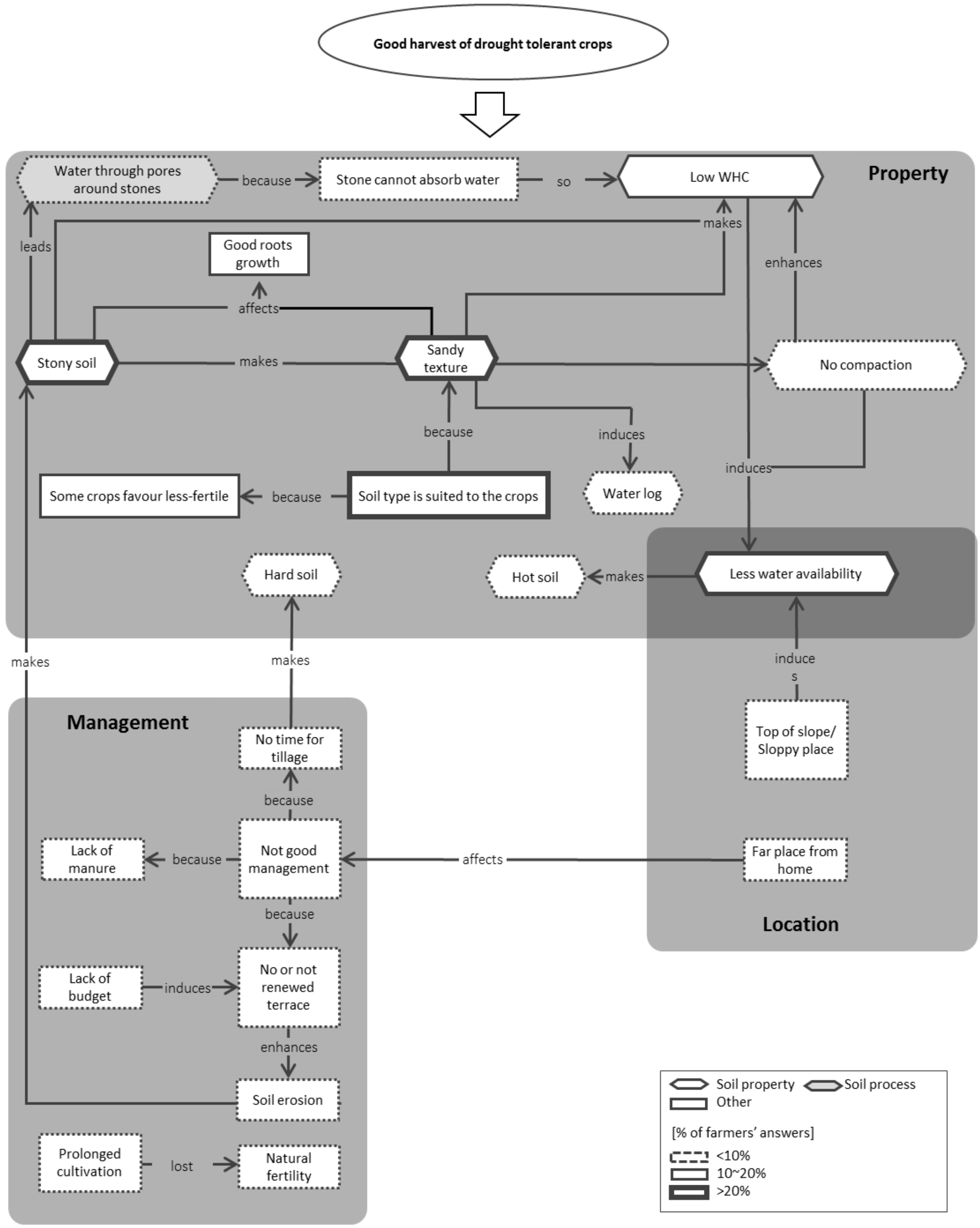


Figure 5-2 Mental model of low fertility soil by Kitui farmers (n=56, source: structured interview with Kitui farmers, August-September 2016)

Table 5-2 Share of key concepts per village for low fertility soil (n=56, source: structured interview with Kitui farmers, August-September 2016)

Category	Concept	Village		Total (%, n=56)
		Village 1 (%, n=27)	Village 2 (%, n=29)	
Property	Low WHC	7	17	13
	Less water availability	26	62	45
	Sandy texture	56	62	59
	Stony soil	15	21	18
	Hot soil	0	14	7
	Hard soil	7	7	7
	No compaction	7	0	4
Process	Water through pores around stones	0	7	4
Management	Lack of manure	4	3	4
	No or not renewed terrace	0	17	9
Location	Top of slope	0	14	7
	Far place from home	4	0	2

Major concepts (≧10% of farmers)

There was much greater agreement among farmers about the key soil properties associated with poor soil fertility. Discussion of soil properties focused on specific types that were characterised as sandy (59%) or stony (18%). 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 (18%). Course textured soil was favourably considered by farmers as allowing good rooting systems (14%). The relationship of soil texture and root growth was also mentioned in the mental model of fertile soil.

Minor concepts (<10% of farmers)

Only a few farmers noted the relationship between coarse soil texture, lack of compaction (4%) and the rate of water penetration (4%). One farmer mentioned waterlogging problems on sandy soil after excessive rainfall. Farmers felt that soils with a low soil water content contributed to their 'hot' soil temperatures in dry conditions (7%).

Management and location were rarely considered as the determinants of low fertility soils, though a few farmers noted that the tops of slopes had less soil water available to crops (7%). Where management was concerned, farmers focused on lack of household money (2%) or manure (4%) as the main constraints on soil improvement, 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%). Some farmers needed to walk long distances to their fields, which was perceived as a reason for poor management (2%).

The difference between villages was also shown the higher number of answers about physical properties (low WHC, less water availability, sandy texture, stony soil and hot soil) in Village 2 than Village 1. The only farmer who mentioned the soil process of infiltration was also in Village 2. They also mentioned topographical features (top of slope) and the influence of a lack of terrace construction on soil degradation. They mentioned antonyms of same concepts from fertile soil. The answers of Village 1 farmers were dominated by coarse texture. Only one farmer mentioned the distance from home in Village 1. One farmer from each village mentioned the lack of manure as a reason why they could not do manure application. Gender differences were not explored throughout this study.

5.4. Discussion

This section firstly considers the portrayal of soil fertility knowledge possessed by farmers in a semi-arid area of Kenya through mental mapping: it examines differences between fertile and low fertility soils, and among farmers; finally, the potential of enhancing soil knowledge exchange between farmers and soil scientists for sustainable soil fertility management is considered.

5.4.1. 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 information that shaped their knowledge of the soil, enabling them to select suitable places for different crops. Holistic farmers' soil knowledge was also observed in other SSA countries. Duvall (2008) emphasizes the fact that Mali farmers create clearer and more detailed classifications of land cover, which they consider as a combination of vegetation and soil types, rather than just as soils. The result is related to the soil fertility-based crop selection in Kenya.

The perceived differences between fertile and low fertility soil implied that farmers considered fertile soil could be created by improved management in targeted areas. Kitui farmers added more soil amendments in fertile places, and a similar trend was observed in other counties in Kenya by Murage et al. (2000). Firstly, farmers would evaluate the water availability in the soil and next, they decided which plots to improve by adding more manure, fertilizers, and labour 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. 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 of fertilizers) 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.

Farmers also placed different emphases on each category when characterising fertile or low fertility soil. 'Water availability' was a key concept in structuring both models. For fertile soil, farmers emphasized the importance of managing their soil to allow enhanced fertility, including the addition of fertiliser or soil and water conservation practice. Good water availability was described as a combination of favourable locations and the soil's good water holding capacity, that was associated with a clayey texture, since soils provide increased water retention and WHC (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 (see Chapter 4), 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.

Even though they belonged to the same ethnic group, the farmers in the two study villages differed in their focus on fertile soils. Farmers in Village 1 emphasized the importance of adding something to soil to increase its fertility, but Village 2 farmers mainly focused on water availability and terrace construction. This reflected the availability of agricultural information in the school 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 (Muyanga and Jayne, 2006) and in such a remote area it was difficult to communicate with extension officers (Anderson, 2006, see detail in Chapter 4 and 7). In contrast, land is more difficult to acquire, buy or rent in Kavuthi because of the area's higher population density, since it is nearer to the town (The County Government of Kitui, 2014) and the availability of black clay soil near the river, made by alluvial deposits, is dominant in Village 2 (see detail in Chapter 4). 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.

Farmers differed, of course, 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 decomposition. They focused mainly on the visual and physical properties of soils and their association with crop yield as the ultimate measure of fertility. It is said that farmers' knowledge is shaped by daily experience (Fry, 2001), which 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 manure rather than leaf mould 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 water holding capacity, and porosity and infiltration. This implies that Kitui farmers have the potential to understand more about soil science.

5.4.2. 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 study also revealed the farmers' potential for understanding further soil scientific information, especially the relationship between soil properties and soil processes. Understanding soil scientific knowledge is useful for them because it explains the systems that enable the soil to support crop production by water movement (storage, drainage and supply to plants) and how soil amendment provides nutrients for plants thorough decomposition (Brady and Weil, 2016).

Texture and water were key concepts in their mental models: these soil properties can be used as good entry points for the two-way communication between farmers and soil scientists that creates hybrid knowledge. Since visual features are well understood by farmers, the use of visual images and videos within participatory extension programmes like Farmer Field School (FFS) (Braun and Duveskog, 2009) would be appropriate. The Global Soil Doctors Programme (http://www.fao.org/global-soil-partnership/pillars-action/2-awareness-raising/soil-doctor/en/) to be run by the Food and Agricultural Organization (FAO) in the near future is one of the good examples: it will provide FFS with posters displaying visual material explaining the role of soil and showing how to manage it in order to maintain sustainable fertility.

The discovery that differences in perceptions depended on location and individuals also emphasized the important role that understanding the environmental and social aspects of a development project site could play in increasing the suitability and sustainability of the project. Learning from local farmers' knowledge is also important for planning site-specific projects. Every location is a unique place and its character is also reflected in local life. Learning a more holistic framework of local soil knowledge from farmers for validation or feedback on language, tools and practice could improve genuine two-way communication and facilitate social learning (Leeuwis and Aarts, 2011; Lie and Servaes, 2015).

With understanding of local farmers' perceptions and demands, the outcomes of the scientific studies and development projects would be suited to local needs. Barrios et al. (2006) noted that while farmers' and scientists' knowledge systems share core concepts, such as the role of water in crop growth, both knowledge systems have gaps and these are complemented by each other (Figure 2-2). Barrios et al. (2006) argued that seeking a balance between scientific precision and local relevance would help to expand shared knowledge and generate new, hybrid knowledge or knowledge systems. Black (2000: 125–126) argued that "*while many traditional problems (e.g. pests) 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 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 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.

5.5. Methodological reflections

This study 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 and Zinck, 2003), so their perception of fertile soils would probably 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 study and in Prager and Curfs (2016) reveals that Andalusian farmers focused 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 indigenous knowledge.

5.6. Conclusion

The creation of mental models was a very successful method of visualizing the Kenyan farmers' understanding of fertile and low fertility soils. The importance of crop productivity, WHC, texture, location and use of organic and inorganic amendments to their mental model was revealed in this study with the particular focus on low WHC for low fertility soils. 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 good descriptions of the process of water holding, infiltration and nutrient accumulation and decomposition. Because farmers already used texture and visual assessments of soils used by soil scientists, using visual materials for the communication of soil scientific knowledge to farmers would enhance their understanding of the systems at work within the soil, by building on this common knowledge. This additional knowledge could enable them to improve site-specific decision-making leading to suitable and sustainable soil fertility management.

The visualization of farmers' knowledge was done in this chapter. The next Chapter 6 shows the mental model of soil scientists for soil fertility which can contrast the similarity and differences between farmers' and soil scientists' perception of soil fertility for accelerating their knowledge exchange.

6. Soil scientists' mental model for soil fertility in East Africa

Abstract

Knowledge exchange between soil scientists and farmers is essential for sustainable soil fertility management. Much attention is paid in the literature to farmers' knowledge. There is less reflection on how scientists' knowledge is constructed through the lens of social science methodology, recognising scientists as actors in sustainable soil management. The mental model approach enables to visualize the hybrid knowledge developed by soil scientists for soil fertility with scientific data, practical experience and communication and to contrast it with farmers' mental model. Data was collected using a causal diagram and individual interviews for the creation of a mental model. These social science methods enable to examine the knowledge system of scientists beyond the research work presented in their scientific papers. Five early career and three established scientists working in SSA participated in this work. Mental models revealed these soil scientists' focus on established scientific concepts in soil science, categorizing soil's chemical, biological and physical properties. They also emphasized the importance of soil management to soil fertility. The soil scientists' knowledge reflected a generalised understanding of processes and functions within soil, underpinning their understanding of potential fertility, particularly biological and chemical processes. The scientists did not use contextual information about specific locations or farms in the discussion, but provided general information about the role of soil forming factors that differ spatially in affecting soil development. There was little evidence of hybrid knowledge developed by integrating their existing knowledge with information from farmers or their own practical experience. This contrasts with my earlier work on farmers' knowledge (Chapter 5), which shows farmers placing greater emphasis on specific site-based contextual information related to their location and the lived experience of actual productivity. Sharing mental models can help to facilitate mutual understanding of soil fertility in order to improve knowledge exchange and enhance sustainable soil management.

6.1. Introduction

Knowledge exchange between scientists and farmers is essential to the enhancement of sustainable soil fertility management, which contributes to many of the UN Sustainable Development Goals (SDGs) (Munyua and Stilwell, 2013; Ramisch, 2014; UN, 2015). Smith et al. (2015) conclude that sufficient scientific knowledge on the improvement of soil management is now available, and that the focus now should be on how best to translate this knowledge into the delivery of sustainable soil management in practice. There is a growing realisation that knowledge sharing is a two-way process, where knowledge is exchanged between the scientific and farming communities and, through incorporation of other sources of information, it is possible to create a hybrid knowledge system (Barrios et al., 2006; Prudat et al., 2018). Whilst attention has been given to understanding farmers' soil knowledge (e.g. Barrera-Bassols and Zinck, 2003; Roland et al., 2018), less emphasis has been placed on using social science methods to understand soil scientists' knowledge systems as hybrid knowledge systems built up from scientific data, practical experience and sharing knowledge with others.

For soil scientists, better communication with non-academic stakeholders can bring challenges that often result from misunderstandings caused by miscommunication (Ramisch, 2014). For instance, Prager and Curfs (2016) demonstrated the differences and similarities between farmers' and scientists' knowledge of soil in Mediterranean areas in Spain through a mental model approach. They showed that farmers in this region more often perceived positive tillage impacts that reduced competition for nutrients and water, whereas soil scientists tended to focus most on soil degradation and production losses. Scientists need to consider why it is important to understand different ways of knowing and understanding the world, and how this appreciation of different knowledge systems could improve communication with other stakeholders and ultimately deliver improvements in soil management relevant to different contexts (Prager and Curfs, 2016). Furthermore, clarification is needed of the extent to which social differentiation and context are reflected in these knowledge systems. Knowledge is most easily understood as a collection of interconnected schemes of interpretation. By accessing new information, humans can learn to reduce uncertainty and try to bring order to the world around them (Davis, 2006). Whilst science itself is the pursuit of understanding 'universal' truth, social science approaches recognise that social knowledge is constructed in a way that acknowledges the importance of nuance (Moon and Blackman, 2014).

Visualisations through diagram-based representations of mental models provide a simple and understandable tool for communicating these types of similarities and differences in knowledge between soil scientists and farmers (Prager and Curfs, 2016; Wood et al., 2012). This study employs the 'semantic web' (Novak and Growin 1984), where a semantic web diagram shows a set of concepts (nouns) as nodes within a network. Directional arrows labelled with relationship terms (mostly verbs) can show relatedness between concept nodes (Wood et al., 2012). This chapter aims to visualise soil scientists' mental model of soil fertility, using social science methods that additionally make it possible to tap into wider hybrid knowledge. Prager and Curfs (2016) used their own mental model, representing the perceptions of interdisciplinary scientists. In this study, data from the participatory approach to and interviews with soil scientists are used, to reflect fundamental concepts of soil fertility from their viewpoint as scientists and as actors in their own right in sustainable soil management. The main objective of this study is to evaluate soil scientists' mental model of soil fertility, within a mixed cropping and livestock farming system with a semi-arid climate. Consideration about how the soil scientists' mental model can contrast to a model of farmers' knowledge of fertile soil created from previous work in similar agro-ecosystems (Chapter 5) and how mental models can be used to enhance knowledge exchange and stimulate improved soil management plans within semi-arid systems in East Africa will be given in the discussion. This approach may help to deliver a more effective and nuanced communication network, where different perceptions are shared among many different actors (Reed et al., 2014).

6.2. Methods

To create the soil scientists' mental model, soil scientists who had experience of soil research in East Africa were purposively selected for data collection, to ensure they had experience of the types of ecosystems studied in Chapter 5. The data was collected during the Wageningen Soil Conference at Wageningen University, the Netherlands, in August 2017. In total, eight soil scientists with experience of soil research in East Africa participated: five early career and three established, six males and two females, six Africans and two Europeans. This study was operated under permission given via the University of Reading's ethical protocol and all participants gave their approval for participation and recording.

Using participatory methods for reflecting fundamental concepts for soil fertility, through a group discussion, five scientists created a causal diagram (Galpin et al. 2000) of soil fertility. All were doctoral candidates: three Ethiopians, one Zambian and one who studied in Kenya, but came from the Netherlands. The scientists were all asked to consider their response in the context of East African soils where the dominant crop was maize, like Kitui. First, they were asked the guiding question: "How (or by what factors) do you recognize the soil as fertile?" They wrote their answers on post-its and put them on a big sheet of white paper. Next, they were asked, “Please actively draw the lines to show the links between these factors.” Finally, the causal diagram with linked concepts about soil fertility was made.

In-depth interviews followed with three additional soil scientists (a professor from the Netherlands, a professor from Ethiopia and a director of a research institute in Kenya), who also had experience of soil research in East Africa. This was done in order to add further opinions to the mental map. They were shown the diagram made in the workshop, and asked, “Are there any items you want to add or remove from this diagram?” The additional information arising from the interviews was added to the diagram.

After the data collection, the linked concepts were sorted and rearranged manually to create a sematic web. The relation terms which connected the concepts were selected from the recorded data, and the soil scientists’ mental model was created. Some narratives during the workshop and interview were transcripts from recorded data, shown as supporting information about their mental model.

The mental model created from the scientists’ knowledge are comparable to the Kitui farmers’ model (Chapter 5) of fertile soil. Both of them were created based on a mixed cropping and livestock farming system with a semi-arid climate. However, data collection and mental model creation processes underpinning differs between studies, notably in that the scientists are asked generally about their knowledge of the region whereas the farmers are asked about knowledge of their farm. Eight people were included in the study here, but 59 farmers were sampled for Chapter 5. All the farmers were interviewed, whereas the scientists took part in participatory workshop. The creation of farmers’ mental model is based on the analysis on coding software but the soil scientists’ one was based on the causal diagram from the workshop. Therefore, taking these limitations into consideration, only high-level similarities and differences will be explored.

Figure 6-1 Photo of participatory workshop (taken in the pre-test at the University of Reading)

6.3. Results

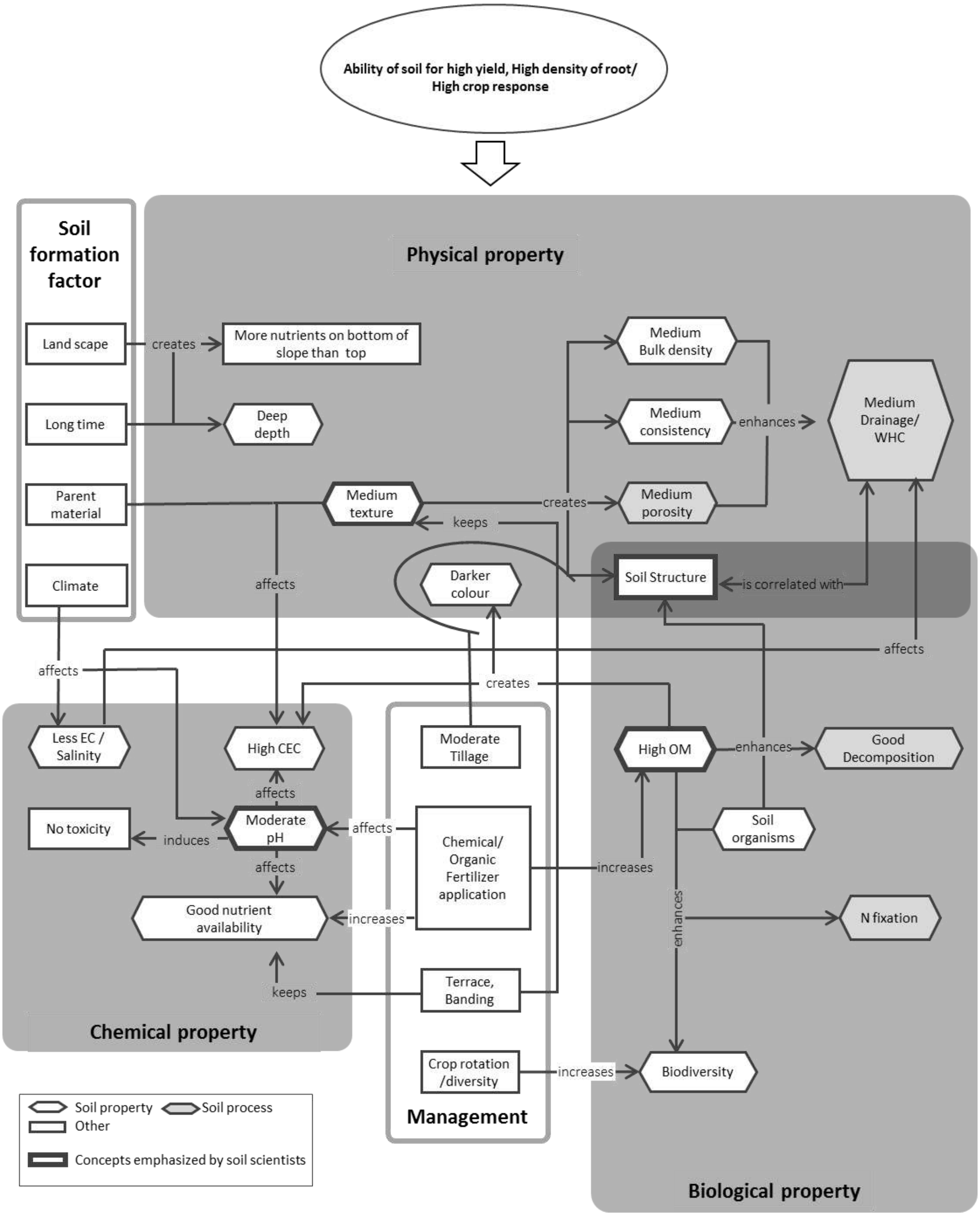


Figure 6-2 Scientists' mental model of soil fertility (n=8, source: group discussion and in-depth interview with soil scientists, August 2016)

The soil scientists started to answer the first question, "How (or by what factors) do you recognize the soil as fertile?" by focusing on good plant performance. They described the components of soil fertility in terms of standard soil science categorizations using physical, chemical and biological properties (Figure 6-2). A particular focus for the scientists was the importance of soil structure, influenced by physical and biological properties; soil structure was related to texture. A loamy (medium) texture was considered better because it provided moderate bulk density, porosity and consistency, which ensured soil water condition: drainage and WHC. Colour was also considered a key physical property of the soil, with darker colours related to higher amounts of organic matter (OM).

In terms of biological properties, more OM was considered as an important indicator of soil fertility. The scientists noted how OM and activity of macro- and micro-organisms affected the construction of the soil structure and the biodiversity of the soil itself, through which the activity of organisms influenced the process of mineralization (i.e. decomposition and nitrogen fixation). Furthermore, in the chemical property part, the scientists highlighted how the amount of OM and 2:1 type clay affected the Cation Exchange Capacity (CEC) and the soil's ability to retain nutrients. A pH value between pH 5.5 and pH 7.5 was considered best for agriculture because it facilitated the release of nutrients including nitrogen, phosphorous and potassium (NPK), micronutrients and exchangeable bases, with less risk of nutrient toxicity, which happened in extremely high and low pH conditions.

The soil scientists also considered the role of farm management in enhancing soil fertility. Examples discussed included the building of terraces to retain nutrient and soil particles, practising moderate tillage to enhance the soil structure, crop rotation to increase soil biodiversity, and application of chemical or organic fertilizers (manure and compost) to increase nutrients and OM, and influence the pH value.

They also considered landscape, noting it as one of key soil forming factors (Jenny, 1941); they reported that fertile soils normally lay at the bottom of a slope. However, they didn't mentioned the specific location and additionally considered other soil forming factors, not mentioned by farmers, which occur on larger spatial and temporal scales, such as the role of climate in affecting EC (rain leaching salts from soil) and pH, the underlying parent material affecting CEC and texture, and the time that this parent material had taken to weather and deepen the soil.

The scientists made some interesting remarks during the workshop and interview to support the construction of their mental model. They emphasized the importance of integration. The first I have quoted concerns the integration of the categories of soil properties: "*There is no meaning of the categorization of soil properties into chemistry, physics and biology. They are organically tied and* *support soil functions.*" (SW3 from Ethiopia, Aug. 2017). The idea was also used to argue the importance of soil structure to soil's physical properties: "*Not only soil texture decides soil physical property. Soil organisms form aggregates from mineral particles and organic matter and create the soil structure. Soil structure increases WHC and stabilization of soil from erosion.*" (SW4 from Kenya. Aug. 2017). In addition to that, the integration of the roles of management for soil fertility improvement, and of OM, bacteria, fungi and micro-/macro-fauna for soil biodiversity, were also mentioned, as written above. In contrast, the definition of low fertility soil was simple: "*just the opposite of fertile soil"*. One scientist said, "*Moderate is important. Parameters that are too high and too low usually make problems like toxicity and deficiency*" (SW5 from the Netherlands, Aug. 2017). Gender and nationality differences on the mental model of soil scientists were not explored throughout this study.

6.4. Discussion

The creation of the mental model of soil scientists who had experience of East Africa revealed the structure of their perception of soil fertility. Its specific characteristics will be discussed before its comparison with the Kitui farmers' mental model of fertile soil in Chapter 5. This process shows hints of the improvement of knowledge exchange between the soil scientists and farmers, and is connected to their collaboration sustainable soil fertility management.

6.4.1. Insights into soil scientists' soil fertility knowledge through mental mapping

The soil scientists' mental model was mainly based on the common concepts of soil science: soil's chemical, biological and physical properties, and soil formation factors. These concepts are discussed in many textbooks (e.g. *The Nature and Properties of Soils*, Brady and Weil, 2016), and soil scientists would have deepened their understanding of the relationships between soil properties and processes during their research. Using this knowledge, acquired from other scientists rather than from farmers, the soil scientists emphasized the importance of integrating chemical, physical and biological factors (e.g. soil structure and nutrient supply). They knew the complex relationships between soil minerals and OM that supported the soil's crop-producing functions. The amounts of OM and soil pH were mentioned as important parameters of soil fertility, because both strongly influenced the stabilization of soil and water and nutrient supply (Brady and Weil, 2016). They also understood the need for balance between the parameters of their model: soil scientists grasped the problems related to excess as well as deficiency.

All the soil scientists who had research experience in East Africa mentioned the importance of management for soil fertility. The importance of collaboration with land managers, including farmers, has been emphasized (Smith et al., 2015) and the soil scientists who worked in the field of development were convinced that this was the right approach. However, the roles of specific location in knowledge was not mentioned and the influence of indigenous knowledge in the soil scientists' knowledge construction was not revealed from this study.

6.4.2. Similarities and Differences between soil scientists' and farmers' mental models of soil fertility

In the knowledge systems of both the soil scientists and farmers there were a number of similarities in perception. They shared an understanding of the essential elements for crop growth including management, water availability and darker soil colour. Good crop performance was a central concept for both mental models of soil fertility (Murage et al., 2000; Vilenskii, 1957). It was reflected that the term "fertility" was used for soil functions that resulted in good production (Brady and Weil, 2016). Water availability is one of the essential requirements for plant growth. Darker soil colour was considered as an indicator of high levels of OM and nutrients (Barrera-Bassols and Zinck, 2003; Brady and Weil, 2016). As mentioned in Chapter 5, Kitui farmers understood the relationship between water availability and soil texture. Darker colour was one of main indicators of fertile soil. The soil scientists clearly mentioned the relationship between OM and darkness and some of the farmers also made that link between darkness and fertility. Therefore, the farmers and the soil scientists shared the concept of two essential elements for plant growth, water and nutrients, derived from physical properties of soils which farmers could understand from their daily experience (Ingram, 2008). To support water and nutrient supply from soils, farm management was considered crucial by both. Sub-Saharan African countries face various soil threats (ITPS, 2015). These include nitrogen and phosphorus deficiency (Gicheru, 2012), soil erosion (Ananda and Herath, 2003) and compaction through limited OM (Rao et al., 2011).

Despite these similarities, there were some important differences to note between the perceptions of the farmers and the soil scientists, which resulted from fundamental differences between their underlying knowledge systems.

In the farmers' mental model for fertile soil, chemical and biological properties were not emphasised. The scientists offered more thorough analysis of chemical and microbiological properties but, understandably, farmers had little access to soil analysis using laboratory equipment (Barrera-Bassols and Zinck, 2003) and did not have a detailed awareness of its availability, due to a lack of extension services in the area (County Government of Kitui, 2013). The scientists also elaborated on the roles of macro organisms for soil fertility, while the farmers did not mention these effects. It can be assumed that activity by beneficial soil organisms, such as termites, was rarely observed in the study sites, so the farmers had not used them as indicators or included them as important. Water availability was, however, mentioned by both groups, but only the soil scientists related this to soil structure and the way it related to micro and macro organisms. This would imply that a knowledge gap remains between the soil scientists and the farmers when using chemical and biological indicators for soil fertility.

The soil scientists' mental model attributed less importance to information about location. Farmers have a holistic view of soils and the surrounding environment (Barrera-Bassols and Zinck, 2003; Ingram et al., 2010), but soil science is classified as a natural science, using a reductionist approach that involves 'breaking down a complex phenomenon into simple parts' (Aikenhead and Ogawa 2007, p.549). One scientific definition of soil fertility is "a soil that is fertile enough to provide adequate root depth, nutrients, oxygen, water and a suitable temperature and no toxicities" (Wild 2003; 51). Within soil science, location is not recognized as 'soil'. It is mainly considered as a soil formation factor (Jenny, 1941). In the soil scientists' mental model, WHC was seen as more important than actual water availability. One scientist in a group discussion reflected that "*crops may not actually grow well on a fertile soil…fertile soils have potential to create good crop production but they are not equal every time with productive soils*" (SG1, Aug. 2017). On the other hand, most farmers could not explain the mechanisms inside soil: "*Pigeon pea is planted because it grows well in the worst fertile place. I know it from my experience but I don't know the specific reasons*" (V1-8, Oct. 2016); "*This soil is good because God created it like that*" (V2-24, Jun. 2016). The differences between the farmers' and the soil scientists' mental models of soil fertility indicate that scientists 'know-why' soil is fertile and farmers 'know-how' to use soils with different levels of fertility (Ingram et al., 2010). In short, in the two cases examined here and in Chapter 5, the farmers and the soil scientists do use similar soil properties to assess fertility; however, the soil scientists have a deeper knowledge of how processes and functions are related to these properties. These differences would create misunderstandings between scientists and farmers and become the barriers in communication that impeded extension (Ramisch, 2014).

6.4.3. Practical use of mental model approach for improved knowledge exchange with soil scientists

The similarities between the concepts in the mental models of farmers and soil scientists imply the potential to improve communication (Prager and Crufts 2016). For instance, there are similar understandings of farm management or soil texture in relation to soil fertility. Management was usually included as 'know-how' knowledge when related to a soil issue. A more holistic approach to knowledge could be a way to expand the understanding of key soil fertility concepts (Barrios et al., 2006) shared between farmers and scientists. In particular, there could be better sharing of information about soil processes or 'know-why' with farmers within Kitui, as this information was lacking from their models (see Chapter 5). However, this may vary from place to place, and farmers' knowledge needs to explored within a region before planning engagements. The local soil classification was performed on a smaller scale than that used in the national soil map, and farmers' evaluations of soil fertility were collated with soil scientific parameters (Barrera-Bassols and Zinck, 2003; see Chapter 4). This contextual detail was absent from the scientific model, that was very generic and not specific to key local soil types. The kind of knowledge brokering needed to bridge these information gaps (Bouma, 2014) would generate a new, hybrid knowledge among both groups (Barrios et al., 2006). Increasing the opportunities for engagement between scientists and farmers would enhance the creation of their hybrid knowledge (e.g. participatory knowledge integration on indicators of soil quality (Barrios and Coutinho, 2012) and farmers' research groups (Alemu et al., 2016)), as well as engagement between farmers and extension officers (see Chapter 7). The soil scientist's mental model is good visual learning material, helping farmers to understand the integrated relationships of soil properties and processes, while the farmers' mental model is a good reference point, giving planners of academic surveys and development projects site-specific information about indigenous perceptions of soil fertility. Mutual understanding of these different knowledge systems can be enhanced by visualization of the different groups' mental models (Prager and Curfs, 2016; Wood et al., 2012) and particularly those of scientists and practitioners responsible for the development of information and communication technologies for agricultural extension (Umar et al., 2015). Because the model was developed within a participatory workshop, participants had instant feedback on the shape of the model. As scientists, copies of the final paper will be share with individuals. Next step is to ask their perception for the comparison between farmers' and soil scientists' mental models and opinions for acceleration of knowledge exchange using mental model approach.

6.5. Methodological reflections

This study focused on the soil scientists who had research experience in East Africa in order to make the best possible comparison between their mental model and that of the farmers. However, there are various areas of specialisation within soil science itself (e.g. soil physics, soil biology, soil chemistry). The creation and comparison of mental models among soil scientists from different areas of soil science would further develop this approach and enrich shared concepts of soil fertility. This chapter also discussed the comparison between the scientists' and the farmers' mental model of fertile soil from Chapter 5, but the methods of data collection and questions asked were different. One conspicuous difference was in sample size: in future, it might be useful to interview a greater number of soil scientists. In addition, as a constructed knowledge depending on many local and personal contingencies, farmers' knowledge within Kitui may differ from that of other farmers in SSA and other locations, even more remote. Further work could explore how questions impact on the data collected: it would be particularly useful to ask scientists more specific questions about their own field sites and experience of practical work working practically with the soil. However, these methods did capture the main features of their perceptions of soil fertility.

6.6. Conclusion

The mental model of soil scientists' perceptions, using social science methods, reflected general information found in scientific textbooks, including more 'know why' than practical 'know how' acquired through experience of working with this soil. These models showed less incorporation of farmers' knowledge into a hybrid system, and perhaps the need for more engagement between farmers and scientists. Many shared concepts, including the importance of crop productivity, water, texture and farm management, were revealed in this study and this implies that the knowledge gap between farmers and scientists studied here is not great and may well have been reducing with the support of extension and research initiatives in the area. The main difference was that scientists emphasised the contribution of biological and chemical processes to soil fertility, whereas farmers focused on the location and lived history of a soil. To develop a hybrid knowledge that can help to generate space for discussing the sustainable soil management options in a particular location, knowledge broking will need to include mental model creation as a practical means for knowledge exchange. This process needs to be repeated with farmers' groups and soil scientists within area where extension work is planned, to ensure good understanding of the indigenous knowledge systems already in place.

7. Rural livelihood diversification and decision-making for soil and climate variability management in Kenya

Abstract

Sustainable soil management is needed for soil conservation. Previous research has revealed that farmers' decisions are affected by multiple factors, including budget, soil types, weather and climate change, and motivation. This chapter examines the relationship between farmers' decision-making for different soil types under climate variability, and how this shapes livelihood diversification strategies. Three different determinants of intention were used to categorised the reasons why farmers made the decisions. Data were collected from 60 farmers across two villages in Kitui County, Kenya, using individual interviews to provide patterns and narratives about farmers' motivations for decision-making. The results showed clusters of livelihood diversification characterised by distance to the nearest urban centre. The diversification clusters influenced different strategies and motivations for various management of soil. Soil type also affects decisions about planting times and varieties of maize, which are underpinned by indigenous knowledge of rainfall and the soil's water holding capacity. However, 54% of farmers in the most vulnerable cluster did not change their management patterns during drought. Distrust of weather forecasts and extension officers limited the extent of their adaptations. In the past, extension officers' promotion of drought tolerant technologies had supported adoption, but now trusted farmers' networks were the main mechanism for sharing experiences of success and failure with chemical fertilizer application and dry planting. These farmers' networks could be a useful mechanism to enhance inclusive processes of communication between extension officers and farmers, creating hybrid knowledge systems for use in soil management, especially for coping with agricultural drought.

7.1. Introduction

Sustainable soil management can make an important contribution to achieving the Sustainable Development Goals (SDGs) because enhanced soil fertility will improve smallholder farming livelihoods, support their food security and help to reduce poverty (UN, 2015; Keesstra et al., 2016; FAO, 2019b). To achieve this, it is necessary to adopt an approach that recognises complex livelihood decisions about soil management by farmers, in order to highlight smallholder constraints and reveal how farmers seek to manage multiple risks to their agricultural productivity (Cooper et al., 2008; Bruyn et al., 2017). Managing crop performance in Sub-Saharan Africa (SSA) is a complex business because multiple factors affect local production, and is characterised by uncertain seasonal rainfall, crop pests and market dynamics (Boko et al., 2007; Hurley, 2010; Hoffman et al., 2018; Lal, 2019). Current climate change impacts continue to increase the risk of soil erosion damage (Below et al., 2010), presenting new management challenges for families already adapted to farming in semi-arid conditions and areas of marginal soil quality (Boko et al., 2007).

While the adoption of new technologies helps to manage new environmental risk, there is also a need to support knowledge sharing between farmers and to ensure regular access by farmers to a range of information about soils, crops, markets, livestock and business skills (FAO and IFAD, 2019). The way that information is presented, its timing, and the type of communication approach used in learning about new knowledge, affect the level of uptake, trust, or adaptation of the farming system, as well as potential risk aversion (Ghadim et al., 2005). However, farmers' adaptation capacity is also a determinant of the speed and quality of the adaptation process, and this is shaped not just by access to information and technology for improved soil management but by social, economic and cultural factors (Smit and Wandel, 2006; Osbahr et al., 2010).

Farmers' decisions on land management not only shape the outcomes for soil fertility but reveal the local motivations for, and barriers to, improved adaptation to climate risk. We recognize there is a challenge involved in conceptualizing this process because farmers' decisions are "neither completely rational, completely irrational, nor completely non-rational" (Guitouni and Martel 1998: 504). When individuals and groups express an intention to act, this is influenced by their perception of the risk, their knowledge and prior experience (Adger et al., 2009), resulting in diversity of response. This diversity is due to the wide variety of control factors in decision-making, which are normally considered as internal (skills, knowledge, background, resources and willpower) and external (location, environmental resources, scale of the problem, availability of assistance, time, money and social expectations and norms) to the decision-maker (Ajzen 2002; Adger et al. 2009). Soil type is a key environmental factor (Barrera-Bassols and Zinck, 2003). Internal factors, including perception of risk, motivation and access to agricultural information, are interconnected with socio-economic factors. This creates a complex web of ever-changing information for farmers to access, filter and then use as a basis for decisions on their own practice.

Theories that explain individual internal decision-making can help to conceptualise this range of factors and provide understanding about why different farming households may decide to adopt different approaches to farming and soil management. For example, the Theory of Planned Behaviour (TPB) highlights three conceptually independent determinants of intention. First, there is personal attitude to behaviour, or an individual's favourable or non-favourable evaluation of the enactment of this behaviour. This will reflect individual perceptions of available resources and understanding of the action. Secondly, subjective norms or social expectations, rules and pressures to perform a particular behaviour (or not) must be considered. Thirdly, there is perceived behavioural control, or the confidence a person has in their capacity to perform a particular behaviour, which is often shaped by past experiences (Ajzen, 1991; Paassen, 2004). These ideas in TPB build on a prior Theory of Reasoned Action (TRA), which argued that the role of intention in performing a behaviour was as important as the actual resources and information available (Ajzen, 1991). Recognising these ideas remains important to any study of soil management: thus, this research adopts the three determinants of intention within TPB as a conceptual lens to organise and explain differential decision-making, using an illustrative case study. By taking this approach, the analysis of the case study is able to move beyond accepted approaches in studies about soil management, that focus on the resources available to farmers (Karanja et al., 2017). Few studies in the area of soil management have actually contextualised the variation of farmers' perceptions as a reflection of individual resources, perceived attitude, subjective norms and perceived behavioural controls, and doing so in this chapter will provide a more thorough explanation of the existing pattern of investment in adaptive crop and soil management (Karanja et al., 2017; Rao et al., 2011). This will offer understanding about how different farmers' perceptions of environmental risk shape on-farm soil management decisions.

This remains an important focus for research, as the Intergovernmental Panel on Climate Change (IPCC, 2014) has highlighted how agriculture in Africa must adapt to inter-annual climate variability in order to cope with longer term climate changes. Using the ideas within TPB suggest that farmers would need to perceive a reason to change as well as have the resources to do so, and research has demonstrated that farmers' perceptions of climate trends do not always match meteorological observations (Ovuka and Lindqvist, 2000; West et al., 2008), making this a complex process. New technologies may help to reduce risk and uncertainty, but adoption and experimentation have been shown to reflect individual experience of on-farm trials, mechanisms for shared learning, personal attitudes to taking risk, and the ability to do so effectively (Ghadim et al., 2005). Thus, the conceptual approach of TPB adopted in this chapter may help to explain why farmers who live in unfavourable areas for farming (due to climate and/or soils) can sometimes be risk averse; it could be that farmers may not believe they have the capacity or knowledge to respond within their agricultural system and instead take limited action or adopt alternative livelihood strategies, such as non-farm activities, in order to cope (Tanaka and Munro, 2014).

Differences in means of communication will also reflect the ideas on personal attitude, subjective norms and perceived capacity controls captured in TPB. Information about soil management comes in multiple forms, including mass media, informal conversations with neighbours and relatives, and consulting agricultural extension officers or extension materials (Adolwa et al., 2012). While it is important to facilitate the communication of information about agricultural management, and soils in particular, between farmers and between different stakeholders, including scientists and extension officers (Yageta et al., 2019), knowledge is constructed from a mixture of both local and external sources of information. Different types of farmers may prefer different sources, and most develop a hybrid understanding that merges local and external ideas (Munyua and Stilwell, 2013). Inequality in access to various types of information or learning opportunities occurs because some communities are remotely situated, transport costs are high (Anderson, 2006), there are few targeted extension activities that poor farmers can act upon (Muyanga and Jayne, 2006), gender and ethnocultural differences raise problems (Ragasa et al., 2013), the cost of accessing information is high, or a limited education leaves people unable to interpret the information format provided (Adolwa et al., 2012). Thus assessing the need for new soil management technologies, and finding the means to adopt them, can be challenging for some types of farmers, who are often female, elderly, or poor, and may be more risk averse in their choice of adaptive action (Donkers et al., 2001). This is despite the fact that different types of farmers share similar perceptions of the impacts of climate change and variability on agriculture (Rao et al., 2011).

To contribute to this challenge of understanding better the implications for farm decision-making and practice of complexity in perceptions of the role of environmental risk to agricultural production, this chapter will adopt the three conceptually independent determinants of intention in TPB to explain factors that influence farmers' decision-making on soil management, using an illustrative example from Kenya. The study will demonstrate how cropping and land management responses to climate variability (particularly to extreme weather in the form of drought) and soil type are shaped by perception of risk, individual motivation and perceived capacity; and whether these reinforce livelihood pathways for different farming households. Thus, empirical analysis is used to develop arguments on the following the three topics: the dominant livelihood strategies and farming systems for different types of farmers;

ways in which soil types and climate, including inter-annual climate variability, change these narratives; and the impacts of information source and communication with extension officers and among farmers for their decision-making, with refer to the new communication approach combining indigenous and scientific knowledge for improve farmers' soil management in a climate change situation.

7.2. Methods

A case study approach was used to enable a deeper understanding of farmers' holistic perspective of their soils on the local scale (Yin, 2013). Kenya was selected because it is a typical sub-Saharan country where agriculture dominates the national economy (Wambugu et al., 2011). Within Kenya, Kitui County was shown by secondary literature to be experiencing agricultural production challenges, due to low-nutrient soils and climate variability (County Government of Kitui, 2013). Kitui County is located 170km east of Nairobi and experiences a semi-arid climate with temperatures between 14℃ to 34℃ (County Government of Kitui, 2014). There are two rainy seasons, a 'long' season between October and December and a 'short' season between March and May, according to local perception, which is opposite to the pattern in the governmental publication (County Government of Kitui, 2014). Annual rainfall for Kitui varies between 250 mm and 1050 mm and the timing within the season can be highly erratic (County Government of Kitui, 2013). Of the residents, 87% earn their livelihoods from agriculture, with a mixed farming system that includes raising livestock and the key crops of maize, cowpea and beans (County Government of Kitui, 2013)

Within Kitui County, two villages were selected using purposive sampling (Tongco, 2007) with respect to four criteria: (a) location in the same soil type (Um19), based on the national soil map, and in the same Agro-Ecological Zone (AEZ) (marginal cotton zone (vs/s+s/vs)); (b) the majority of villagers engaged in small-scale farming; (c) different distances from Kitui town centre and different frequency of communication with extension workers (that in the closest being higher than in the more remote location); (d) no active NGO activity or agricultural extension project. It was also assumed that the distance from Kitui town would influence access to markets and market information, although farmers could receive information through radio (Anderson, 2006). Using ArcGIS, the national soil map and AEZ map (Sombroek et al., 1980) were combined with a road map (WFP, 2007) of Kenya to identify potential villages. Based on the mapping and preliminary village visits, Village 1 (Kavuti) and Village 2 (Kitambasyee) were selected. On the national soil map of Kenya (Sombroek et al. 1980), the area is part of Um19, well drained, moderately deep to deep dark reddish brown to dark yellowish brown, friable to firm, sandy clay to clay; in many places with top soils of loamy sand to sandy loam (ferralo-chromic/ orthic/ ferric Acrisols; with Luvisols and Ferralsols).The AEZ of the selected area is a marginal cotton zone (vs/s+s/vs) (Ralph et al., 2006). According to GPS data, the elevations of the two villages are similar: approximately 1180m in Village 1 and 1000m in Village 2, with a similar slope in the farms of both areas (0 to 25%) (Soil Survey Division Staff, 2017). Village 1 was located nearest to Kitui town centre at 4.5 km, with historically frequent direct communication with extension workers. Village 2 was further away from Kitui town at 20km, with villagers using public buses, motorbikes or taking a two hour walk to reach the town. It had limited experience of direct contact with extension workers. A detailed description of the study location can be found in Yageta et al. (2019).

Data collection was conducted between January 2016 and October 2016. Structured questionnaire and open questions were used in each individual farmer's interview to identify: 1) household characteristics, including income sources and numbers of cultivated fields and livestock; 2) soil types and fertility evaluation of their lands; 3) soil management practices used on home fields and away fields; 4) timing of soil management (e.g. before or after rain, during the long or short rain season, whether these reflected practice for managing drought and excessive rain conditions, historical change during the last 10 years); 5) reasons for management strategy; and 6) sources of information that influenced farm management. Open questions were included in theme 5 to collect farmers' narratives. Households were randomly sampled within each location, and within each household the person who made the field management decisions (usually the household head or wife) was purposively selected for interview. In total, 60 farmers were interviewed (30 farmers in each village). The two agricultural extension officers who covered each sampled village were interviewed. Data collection was conducted with support from a locally trained translator (between English and KiKamba), although some farmers preferred to answer in English. Permission was given via University ethical protocol and by the Kenyan National Commission for Science, Technology and Innovation (NACOSTI).

For the purposes of this chapter, households was classified into groups with similar livelihood strategies, using cluster analysis within SPSS 21.0, with a particular focus on income-earning aspects of livelihood, following the approach of Iiyama et al. (2008) and Freeman and Ellis (2005). Cluster analysis was performed by the Ward method using the contribution rate of each income source (food crops, fruit and vegetables, livestock, and off-farm activity) to total income, types of off-farm income (regular employment and casual labour, remittance was divided into the two categories based on the periodicity), the number of cows/bulls owned and the number of cultivated fields. Types of income sources were analysed for amount and timing. Other assets were included in the analysis, such as livestock and land. Cows and bulls were treated as main long-term assets. The number of cultivated fields had a positive correlation with the total cultivated area: many farmers in the study area did not know the exact values.

On SPSS 21.0, the collected data was sorted and the types of off-farm income was converted into numerical values (regular employment: 1 and casual labour: 2). To balance the volume of data on the ward method, standardization option was selected in SPSS operation.

Qualitative data from the structured interviews was analysed using thematic coding (Coffey and Atkinson, 1996), using SPSS 21.0, Excel 2016 and Word 2016 to reveal the share of respondents who mentioned their practices and reasons at least once. Narratives from the different forms of analysis were then organised to explain identified patterns.

7.3. Results

The results first presented dominant livelihood strategies and farming systems for different types of farmers, with particular attention to decision-making on staple maize production and in relation to soil type and seasonal rainfall. The variations on farmers' decisions on maize variety selection, timing of seeding, manure and chemical fertilizer application as general management was described with the reasons of their choices. It is then important to consider how inter-annual climate variability may change these narratives, for example under drought or wetter conditions. The influence of different agricultural information sources is examined in the last section.

7.3.1. Characterising Livelihood Strategies

Cluster analysis of the full dataset revealed four distinct clusters that characterised different livelihood strategies adopted by households in the study (Table 7-1). Cluster 1 characterised a livelihood strategy of specialization in off-farm income activities. Households within Cluster 1 relied on money from off-farm employment, a small number of cattle and a small farm. Cluster 2 characterised fruits and vegetable farmers, whose income was generated from fruit and vegetable sales. These households had few cattle and more intensively managed small farms. Cluster 3 characterised households with a diverse portfolio of livelihood strategies, including off-farm income activities and crop farming, but with relatively larger numbers of livestock than found in other clusters. These households farmed extensively across their larger farms and relied on ad hoc livelihood diversification to make a living and manage risk, for example by earning money from temporary labour or selling crops and animals. Cluster 4 also characterised households with a diverse livelihood portfolio of off-farm income activities, crop farming and livestock, but this cluster had only a small number of animals and small farms compared to Cluster

3, and overall income was low. The clusters reflected the farming and livelihood challenges as shaped by the spatial location of the study villages. For example, Clusters 1 and 2 were predominantly households from Village 1, which was closer to Kitui town and market centre, while households in Clusters 3 and 4 were mainly from Village 2, which was further away from the market and alternative employment options.

Table 7-1 Identified clusters of livelihoods diversification strategies in the study area (n=60, source: structured interview data 2016)

	Cluster 1: Specialization in off-farm income	Cluster 2: Fruit and vegetable farming	Cluster 3: Combination of off-farm and mixed farming on a large scale	Cluster 4: Combination of off-farm and mixed farming on a small scale
No. (%) of households	23 (38%)	7 (12%)	17 (28%)	13 (22%)
No. for Village 1: Village 2	21:4	7:0	2:15	1:12
Contribution to total income (%)				
Food crops	1	0	19	29
Fruit and vegetables	7	63	5	4
Livestock	2	6	17	12
Off-farm activities	91	31	50	49
Main off-farm income type	regular	casual	regular	regular
Average no. cows/bulls	1	0	5	0
Average no. cultivated fields	1	2	3	2

7.3.2. Understanding soil and crop management

According to an overview of soil management in the study area, all farmers interviewed practised mixed cropping on their fields. On an average of sampled field data (n=60, S.D=3.34), seven different crops were planted in one field, with a maximum of 16 and a minimum of one. The most popular crops were maize, pigeon pea, cowpea, beans, pumpkins, cassava, and green gram respectively. Of the farmers, 88% relied on animal manure as an organic treatment to fertilise their soil. Across all clusters, 41.7% of farmers applied chemical fertilizer at the time of planting and when the grain matured. Digging terraces into fields was routinely practised in order to protect against soil erosion and improve water holding capacity. While this practice required labour investment, it was less costly than constant use of chemical fertiliser. Farmers dug the soil manually using a hoe, or used an ox-plough to prepare for seeding. Only two farmers hired a tractor to plough. The details and determinants will be explored in section 4.1 and reflect willingness, ability to invest and the livelihood strategy followed. The land management approach used in the study villages was similar to that in other areas of the district (Ralpph et al., 2006, County Government of Kitui 2013).

Farmers selected crop types to suit the soil within each field, and this reflected soil types across their whole farm for each rainy season. An example of a seasonal calendar for crop selection is illustrated in Figure 7-1. It shows that cash crops, including maize, green gram and vegetables, were planted preferentially in the areas perceived to have the most fertile soil, while pigeon pea and sorghum were planted in those areas perceived to be less fertile and with sandy soils. The crops planted on sandy soil were perceived to have a better drought tolerance. All farmers in the study locations adopted a similar approach.

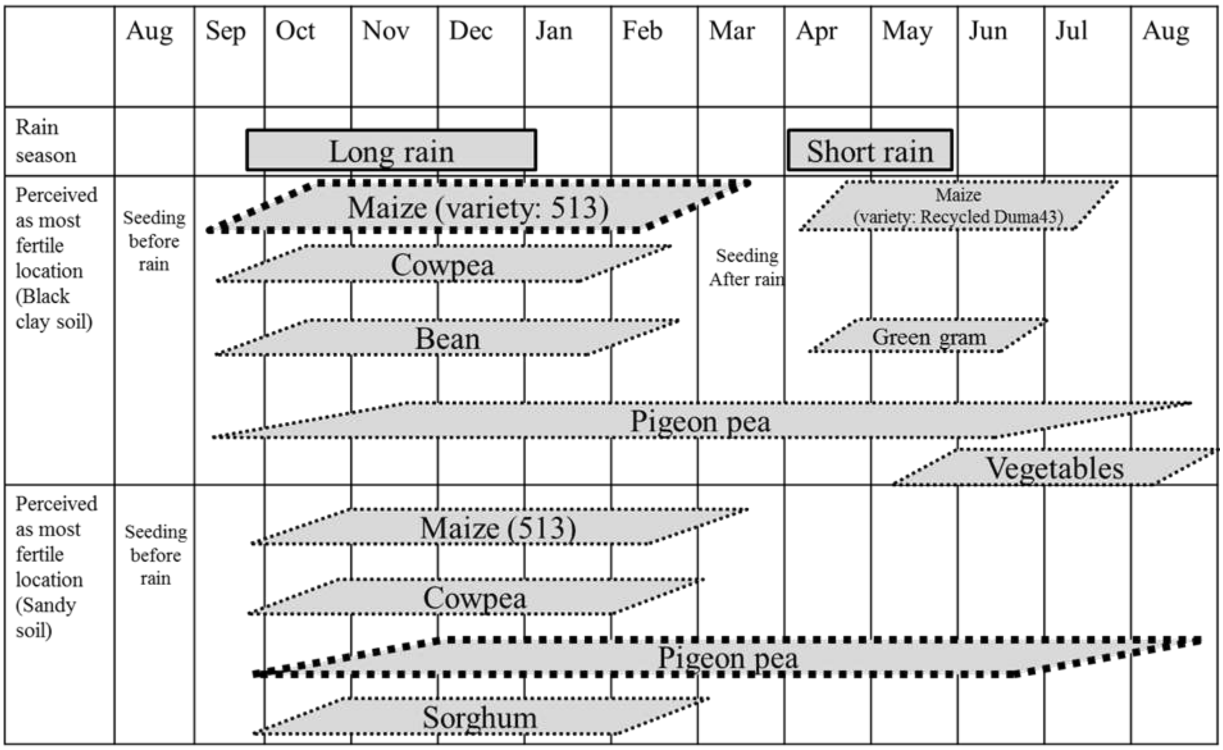


Figure 7-1 An example of seasonal crop selection (Source: structured interview for V2_18; the bold dashed lines on the boxes indicate the main crop in each field.)

7.3.3. Differences in farming management determined by livelihood strategy

The study of different management based on different livelihoods focuses on maize variety selection, and the timing of seeding and manure and fertilizer application. Although there are different crops within the mixed farming system, this chapter focuses on maize because it is the staple food crop and one of the main cash crops. Farmers combined not only crop types but also varieties of crops in a field.

Maize variety selection

Maize variety selection showed a high level of individuality, with 17 different strategies followed for the long rain and 16 for the short rain season. Farmers preferred a high yield hybrid maize variety (e.g. Duma 43, 513 and DK8031) for the long rain season. For the short rain season, farmers instead selected varieties that were early maturing and drought tolerant (e.g. DH01, DH02, DH04 and KDV1), and this included local varieties (e.g. India and Makueni) and recycled hybrid varieties that displayed these characteristics; in some cases, farmers decided not to cultivate maize at all because the short rains were perceived as too risky. Of the farmers surveyed, 68.4 % adjusted maize variety selection to suit the perceived level of soil fertility for their individual farm. Farmers chose high yield maize varieties for fertile soil and early maturing or resilient varieties for less fertile soil. Thus, selection of maize variety reflected farmers' perception of the environmental risk and distribution of soil type. The further analysis found a difference in the use of pure hybrid seeds between Clusters 1 and 2 and Clusters 3 and 4 (Table 7-2). In both Clusters 1 and 2, 57% of farmers used only hybrid seeds. However, in Clusters 3 and 4, this rate was 18% and 8% respectively. In total, 33% of farmers used just pure hybrid maize and 8% used just the local maize variety. The other farmers used mixed maize varieties including hybrid, recycled hybrid, local and other varieties coming from outside. Farmers' reasons for refusing to use hybrid seeds exclusively could be categorised as high cost (36%), uncertainty of the amount of rainfall and value of the investment (32%), satisfaction with current yield without using the new varieties (28%), and a poor prior experience when using hybrid seeds (4%) (although the poor harvest may not be attributable to the seed itself). Illustrative quotations from these farmers appear in Table 7-3.

Table 7-2 Use of hybrid maize varieties on each cluster (n=60, source: structured interview data 2016)

Maize selection	Cluster 1: off-farm income	Cluster 2: vegetable and fruit farming	Cluster 3: crop/animal/off-farm (large)	Cluster 4: crop/animal/off-farm (small)
Only pure hybrid maize variety used (%)	57	57	18	8
Mixture of maize varieties (hybrid, recycled, local, external) (%)	43	43	82	92

Table 7-3 Farmers' reasons for not relying on pure hybrid maize varieties (n=25, source: structured interview data 2016)

Theme (% of farmers reporting from sample)	Illustrative quotes
Cost (36%)	"*I don't have enough money to buy hybrid maize seeds. If I can use it, I can have more yield*" (V2_1, Cluster 1)
Uncertainty of rains (32%)	"*The rain amount in the short rain season is less and I cannot depend on it*" (V1_26, Cluster 2) "*In the short rain, I just use recycled DH02. If rain is sufficient, I can have a harvest*" (V2_4, Cluster 4)
Satisfaction with existing yield (28%)	"*I don't need a lot of harvest because it is just for me and my husband*" (V2_30, Cluster 3) "*I don't really mind the harvest in the short rain season. I usually get enough yield in the long rain season*" (V1_1, Cluster 1) "*In 2007, I planted a local maize but the rain was very short and no maize remained for seeds. It was much trouble but I didn't have money to buy hybrid seeds so I bought the variety 'India' in Kisasi. I tried it and recognized it was very early maturing and it had a very good performance in my field so I continue to use it. I am satisfied with 'India' and it is possible to recycle the seeds*" (V2_12, Cluster 3)
Poor prior experience (4%)	"*I saw another house use hybrid seed and I thought it is too 'brittle' for muthokoi (local maize dish) and it is easily affected by pests sometimes. I think about trying to use hybrid but I will not try it again actually*" (V2_21, Cluster 4)

Timing of seeding

The timing of planting the seeds was influenced by the timing and amount of rain, the soil types, and experience of success or failure in seeding before the rains (dry planting in anticipation that the rains would come soon). The analysis found four types of timing of seeding by farmers: before the seasonal rain had started; after the rain had started; both before and after; and timing unaffected by rain. In Clusters 1 and 2, 52% and 57% of farmers, respectively, planted before the rain started, while in Clusters 3 and 4, 59% and 54% of farmers, respectively, planted after rain.

Table 7-4 highlights reasons farmers gave for their decisions. The main reason for planting before the rain started was to ensure the crop could maximise the use of available water. Other reasons were limited labour availability, an early harvest, that it was easier to plant the seeds without rain, and that it helped to reduce the risk of the rain washing the seeds away. According to farmers in the sample, the main reason for seeding after the rain was that seeds could rot while waiting for sufficient rain to fall (9%, 35% and 23% in Cluster 1, 3 and 4). Farmers reported germination failures using shallow ploughing, then seeding without making holes for the seeds (personal communication, Agricultural Extension

Officer Village 2). The farmers who planted seeds both before and after rain based their decisions on timing on location and soil type, which affected workability. Other, less frequently cited, reasons for the timing of seeding were availability of labour and seed: in these cases, the timing of the rain was irrelevant.

Table 7-4 Farmers' comments about reasons for each planting time (n=60, source: structured and open-ended interview data 2016)

Theme (% of farmers reporting from sample)	Illustrative quotes
Before rain (43%)	"*Planting seeds before the rain will use all the rain*" (V1_29, Cluster 1) "*After the rains come, we need to do a lot of work with the livestock*" (V1_16, Cluster 3) "*If I plant in the dry season there is no problem…there is some wash but some seeds will remain afterwards to grow. But seeding after the rain will mean it is all washed away by the next rain. Seeding before rain also makes us to avoid eating maize seeds for next season*" (V2_21, Cluster 4)
After rain (38%)	"*Some crops were lost when I tried seeding before rain. My neighbours had the same problem. When I plant seeds after rain, all seeds grow*" (V2_29, Cluster 3) "*Chickens are free to roam during the dry season and it is easy for them to eat the seed from the loose soil*" (V1_11, Cluster 1) "*Dry season requires labour for the house, to dig and make a terrace*" (V1_19, Cluster 2) "*If seeding before the rains start… plough is shallower than after rain because of the hardness of the soil. Shallow ploughing increases the risk of rain washing the seeds away*" (V2_27, Cluster 3) "*field is hard before the rains, but after the rain it is easy to plough*" (V1_8, Cluster 1)
Both during, before and after (15%)	*"[Planting] before the rain gives a better harvest…can use all the rain…but you cannot finish all planting in the dry season because of limited household labour*" (V1_18, Cluster 1) "*Seeding before the rain is done in Ĩlimba (black clay soil) and after in the fields near the home… ploughing in dry soil is good…. the seeds grow when the rain starts so there is no problem for them to germinate…soil is loose and make cracks when it is dry. Nthangathĩ (sandy soil) becomes soft after the rain and I plant after the rain here so it grows well. Because the soil is dry still at the start of the rains it can make the top soil hard*" (V2_18, Cluster 3)
Un- affected rain (3%)	"*Planting seeds either before or after rain is no problem but it depends on the amount of other work*" (V1_2, Cluster 2) "*The time of seeding depends on when I have seed...but I prefer to seed before rain because of a good harvest*" (V1_9, Cluster 1)

Manure

Of the farmers in the sample, 88% used manure but the way the manure was applied differed between Clusters. In Clusters 1 and 2, 56% and 57% of farmers respectively put manure into holes in the soil with the seed at the time of planting, while in Clusters 3 and 4, 73% and 54% of farmers respectively spread the manure over the soil surface. The different ways of applying manure reflected different availability of manure and access to land between the Clusters. Land in Clusters 1 and 2 was limited and there was less livestock, so farmers tried to use manure in an efficient way ("*Putting manure into the hole with the seeds has the benefit of trapping any water and the nutrient supply needed for germination*" Agriculture Extension Officer Village 2). Meanwhile, in Cluster 3 in particular, there was more livestock. Spreading manure was easier because it needed less labour.

Chemical fertilizer

The use of chemical fertilizer also differed between Clusters. In Clusters 1 and 2, 74% and 86% of farmers respectively applied chemical fertilizer: "*The reason for using fertilizer is that it gives a good harvest and more cobs when used with hybrid seeds…in the past, the amount of rain was plenty so local maize grew well but the amount of rain has decreased nowadays and we need hybrid seeds which only grow well with fertilization… to ensure a good harvest*" (V1_7, Cluster 1). However, in Clusters 3 and 4 only 6% and 8% of farmers respectively used chemical fertilizer. This difference between Clusters 1 and 2 and Clusters 3 and 4 may also be explained by differences in information availability (see section 7.3.5) or misinformation ("*I was told by a person in Machakos said that if I use fertilizer, I will need to use it continuously and if I stop using it, there will be no harvest…currently my soil is fertile so there is no need"* V2_18, Cluster 3). A small proportion of farmers were not able to access chemical fertilisers due to cost (13%, 14% and 18% of Clusters 1, 2 and 3 respectively).

7.3.4. Effects of climate variability on farmers' decisions about land management

Both inter-annual variation and intra-annual variations in rainfall influenced farmers' decisions about crop selection and application of fertilizers and pesticides (as for intra-annual variations, see section 7.3.2). While drought occurs frequently during the short rain season, and excessive rainfall can occur in the long rain season, there may be differences between years in these patterns. For example, the intensity of rainfall during events was perceived by farmers to have increased compared to 10 years ago. While farmers changed land management strategies subtly during periods of low rainfall within one season, the majority of farmers did not consider intense prolonged rainfall a reason to change their land management strategy, as variability was considered positive if there was sufficient rainfall overall for crops (Table 7-5).

Table 7-5 Changes in land management under climate variability (n=60, multiple answers allowed, source: structured interview data 2016)

Land management strategy	Cluster 1: off-farm income	Cluster 2: vegetable and fruit farming	Cluster 3: crop/animal/off-farm (large)	Cluster 4: crop/anima/ off-farm (small)
Change in low rainfall year (% in each Cluster)				
Change crop	22	29	6	0
If maize does not grow well, cut all maize for livestock fodder	0	0	6	8
Less fertilizer	61	43	6	8
Add fertilizer or manure	8	0	0	0
No or less pesticide	0	0	30	31
Not hire labour (stop cultivating)	4	0	0	0
Not plant in short rain if rain is late	8	0	0	0
Watering of crops	4	14	0	0
Harvest early to eat green product	4	0	0	0
Increase spacing between maize	0	0	6	0
No change in practice	22	43	53	54
Change in excessive rain year (% in each Cluster)				
Fertilize early	4	0	0	0
More fertilizer or manure	13	14	0	0
Prevent soil erosion (renew terrace, plant *Nepia* grass)	4	29	0	0
No change in practice	74	71	100	100

When the rains were poor, the main adjustment in Clusters 1 and 2 was to apply less chemical fertilizer (61% and 43%), while in Clusters 3 and 4, the main adjustment was to use less pesticide (30% and 31%). Farmers reported changing use because they perceived a poor performance in the crop and did not want to waste resources, not because of lower rainfall. For example, "*When the amount of rain was small, the size of maize was still small at the time for fertilizer application. It implied no harvest so I didn't applied fertilizer*" (V1_4, Cluster 2); "*In the lower rain year, I didn't spray pesticide for green gram and cowpea because they dried up. I sprayed it just for pigeon pea*" (V2_8, Cluster 4). This implies that decisions were influenced by economic reasons and to avoid investing money if there was a perceived risk of crop failure and agricultural drought.

Just 8% of farmers in Cluster 1 increased their application of fertilizer and manure during periods of low rainfall within a rainy season. This included a former chief in the area and a teacher who had access to extension information; this reflects elite capture of information: "*My brother is an extension officer so I can call him if I have questions*" (V1_10, Cluster 1). These households also had the financial ability to apply fertilizer and manure, and the educational qualifications to interpret information from extension officers, which they claimed helped to reduce the risk of lower yields.

Others used a different type of crop, such as changing the variety of maize from Duma 43 to DH02 (22%, 29% and 6% in Clusters 1, 2 and 3 respectively). Maize varieties were changed, following a delay to the start of the short rain season, by farmers who usually seeded after rain. These adaptable farmers can be categorised into two groups: those in frequent communication with an extension officer, and those with poor households but high motivation to try new methods. The latter group focused on their perception that external information was important and they were open to experimenting with new ideas: "*During my work on a big farm, I saw new methods and new varieties of cash crops. So, I know how to do it and try at home to increase income from my farm*" (V1_19, Cluster 2); "*When I heard there was a meeting with an extension officer in the other area, even if I had another item on my schedule, I cancelled it and attended the meeting. Listening to new information is very important*" (V1_16, Cluster 3). Other changes farmers made were not to plant if there was low rainfall, to cut maize stems for livestock fodder, or to harvest early. Farmers who were watering crops and followed a strategy of intensively managing their farms for fruit and vegetables (4% and 14% in Clusters 1 and 2) were able to plant regardless of gaps in rainfall. Their fields were located close to water sources, making manual watering feasible. These patterns reflected the inequalities that existed in the communities, for example in land tenure, and how these were reinforced by the impacts of climate change and variability. Accessibility to water sources or soils with good water retention will become more valuable if climate variability increases.

It is important to note that 22%, 43%, 53% and 54% of the farmers in Clusters 1, 2, 3 and 4 respectively did not change their management in lower rainfall years. Farmers reported that they expected a risk of low rainfall in the short rain season and were already managing their farms to avoid a loss at that time (e.g. deciding not to plant, using drought tolerant varieties, or seeding maize before the rains). This management focused on planting drought tolerant varieties selected for the different soil types with different water holding capacity (see section 7.5).

Following excessive rainfall events, the majority of farmers (74%, 71%, 100% and 100% in Clusters 1, 2, 3 and 4 respectively) did not change their management (Table 7-5) because these events were perceived as lower risks to production than drought spells during the growing season in the study area under semi-arid climate. Adding more fertilizer and soil protection practices, such as renewing terraces and planting *Nepia* grass, were routinely undertaken, and this helped to prevent soil and nutrients being washed away by excessive runoff. Farmers who applied a second fertilizer earlier or added more manure reported stagnation in maize growth during times of excessive rain and switched their focus to other crops. This was reported particularly by farmers in Clusters 1 and 2 in Village 1 during intensive rainfall periods: "*I apply fertilizer earlier when there is plenty of rain to strengthen the maize earlier*" (V1_20, Cluster 1); *"I am afraid that fertilizers are washed away by rain so I add more and renew terraces sooner when there is excessive rain*" (V1_2, Cluster 2). Their perceptions were shaped by their prior experience of solving problems; previous success in protecting crop production from climate extremes gave farmers more confidence to experiment with their management.

In both climate extremes of drought or heavy rain, farmers in Cluster 2 were more pro-active in making changes than in Cluster 1 (e.g. changing crop type or irrigating during a drought, and adding more fertilizer or soil protection during heavy rainfall). This reflected the main livelihood strategy adopted, where farmers were more dependent on income from their farms and willing to invest in farm management and soil protection. In contrast, farmers in Cluster 3 and 4 reported lack of time, lack of labour and the cost of agriculture as constraints. However, diversified income sources for these more remote locations prevented farmers from perceiving investment as a priority. Furthermore, Cluster 3 had larger farms extensively managed, with a reliance on off-farm income, so production loss during climate extremes was less important to their overall livelihood approach. Diversified livelihoods influenced personal attitudes to the value of investing in farm management.

7.3.5. Differences in information sources and management practice

An extension officer was the main source of crop information for 57%, 29%, 35% and 31% of farmers in Clusters 1, 2, 3 and 4, respectively. Family and neighbours were important sources of crop information for all Clusters. Agrobet (an agricultural material shop) was reported as a valuable source in Clusters 2 and 4 (14% and 18%). The radio was used more in Village 2 than Village 1, so farmers reported this as important in Cluster 3 and 4 (35% and 15%). In Clusters 1, 2 and 4 (4%, 14% and 8%), farmers reported gaining information about new crop varieties during casual labour on neighbouring farms. Social networks remained valuable in facilitating access to information: *"Communication with friends in different places (e.g. Nairobi, Machakos and Kikuyu) is the best way to increase information about new technology"* (V2_18, Cluster 3).

General guidance about manure application came from other family members in all Clusters (57%, 29%, 53% and 54% respectively) and farmers felt this was common indigenous knowledge. However, precise application of manure into the seed hole was perceived as a more recent practice, with 17%, 29%, 18%

and 15% in Clusters 1, 2, 3 and 4 learning this new knowledge from local extension officers, and 13% and 14% in Clusters 1 and 2 learning this information from school.

Information sources for chemical fertiliser use also differed between Clusters 1 and 2 and Clusters 3 and 4. In Clusters 1 and 2, 30% and 29% of farmers in the study received information from the extension officers, 26% and 14% from family, and 4% and 29% during work on other farms. Agrobet (14% in Cluster 2) and school (17% in Cluster 1) were also sources for chemical fertilizer use. However, in Clusters 3 and 4, 47% and 62% felt that they did not have clear information about how much, or when, to apply chemical fertilizer. Kinship and friendship networks were used but could lead to misinformation and more reliable information was perceived to come from extension officers (24% and 23% of farmers in Clusters 3 and 4) or via the radio (6% in Cluster 3), even though they had limited access (see section 7.3.3).

In a time of climate variability, farmers' confidence in the radio weather forecasts also affected decisions about whether to apply fertiliser or change crop type (n=41, 78% of sampled farmers did not trust the radio weather forecasts because they had not been accurate in the past) (Table 7-6).

Table 7-6 Farmers' perceptions of weather forecast information (n=41, source: in-depth interview data 2016)

Theme (% of farmers reporting from sample)	Illustrative quotations
Negative (78%)	"*I don't trust wrong information. In the past, they said less rain and recommended more sorghum but there was plenty of rain and you would have got less maize by following wrong information*" (V2_21, Cluster 4) "*Rain depends on God, not men*" (V1_18, Cluster 1) *"I continue to listen to weather forecasts but not use them for decision-making. I don't trust it"* (V1_17, Cluster 3) "*Weather forecast information is wrong*" (V1_26, Cluster 2)
Positive (17%)	"*I trust it because it said El Nino came and it came actually*" (V1_20, Cluster 1) "*If rain is plenty, I know before the weather forecast but it says the same"* (V2_6, Cluster 3)
Neutral (5%)	"*Sometime true, sometime fail*" (V2_27, Cluster 3)

External knowledge about new agricultural technologies was valuable for adaptation to climate change and variability but extension services suffered limited budget and staff, restricting their ability to communicate directly with farmers on a regular basis: "*Government policy has reduced the number of extension officers per sub-County following the introduction of a County system... budget for* *transportation is not enough so we cannot meet the requests for a visit*" (personal communication, Extension Officer for Village 1). The decrease in opportunities for communication and follow-up affected farmers' trust in extension information as evidenced by the differences between the villages. Village 1 has a history of house visits by extension workers during the 1980s and 1990s (personal communication, Agricultural Officer, Ministry of Agriculture, Kitui County office), so trust in external knowledge is high ("*in the past, the extension officer saw the local way and the lost production so they instructed us on how to get a good yield. It was like dark became light*" V1_12) but demand remains high (*"I want to ask many questions to extension officers but I cannot. My father's generation had more opportunity to meet them"* V1_20). This change has fostered individual autonomous adaptation responses and a shift to increased awareness of farmers' networks. For example, a pioneer farmer in Village 1 (V1-29) noted "*When I know farmers who do good management, I visit them and ask questions about their management. The best farmers have better information than extension workers who know theory*". Village 2 had no history of extension visits and the relationship between farmers and extension workers was not developed; neither was trust in information reported. To manage, farmers reported that they had relied on their own knowledge or developed alternative off-farm strategies. The results highlight the value of re-connecting technical scientific information from extension workers with farmers' practical experience. As described above, there are already diverse agricultural decisions being made and climatic extremes are forcing farmers to consider more varied options on their field practices, which multiple sources of information could support.

7.4. Discussion

This section seeks to explore the connections between different livelihood types and location, soil and climate variability, together with the role of information sources for decision-making about land management practice. These dimensions are framed by reflections on the components of TPB that examine the importance of independent determinants of intention (personal attitude, subjective norms or social expectations, perceived behavioural control or confidence) and how these relate to farmers' decision-making. The discussion considers the implications of the results for future extension support.

7.4.1. Management by different livelihood strategy and location

Farmers in the study area experienced similar environmental risks from drought and low soil fertility, but the livelihood risk was different among villages and the four livelihood clusters identified. The effects of the villages' location on livelihood strategy (see Table 7-1) and communication of agricultural knowledge have been shown. These differences influenced decision-making on soil management options and investment. Cluster 1 and 2 showed more ability to integrate external knowledge with their existing practice than Cluster 3 and 4. Increases in household income and opportunities for communication with extension officers are likely to increase effective adaptation strategies (Ramisch, 2014). For households with small farms, effective intensification of limited land has become a major priority and farmers have focused on vegetable and fruit production for sale. In contrast, farmers in Cluster 3 and 4, who mainly live in Village 2, with limited opportunity to generate cash income and limited access to extension officers, have reduced their use of external inputs. The availability of land and the supply of livestock manure in more remote locations have become important factors in these farmers' decision to retain extensive farming with minimum investment, as they perceive a need for risk avoidance. Many have sought out alternative off-farm livelihoods or cope on a day-to-day basis.

Farmers' decision-making about soil and crop management was shaped by local subjective norms, such as the promotion of chemical fertilizer by extension services (see section 7.5): individual experiences of success or failure when using these new methods reinforced perceived behavioural control (see section 7.5). Perceived behavioural control was also reinforced by miscommunication between farmers or between farmers and external actors, as well as the incompatibility of new approaches with the different soils or under variable conditions. This narrative has been reported elsewhere (Ramisch, 2014) and explains why bad experiences with new technology create an associated tendency to believe that the farmer is inherently unable to adopt innovations, and that the technology is weak, instead of finding the cause in environmental variability. Unwillingness to follow up with extension officers prevents farmers from building the necessary capacity to innovate. Regardless of the different land availability, farmers in Cluster 4 seemed to follow the management strategy of Cluster 3. It implied that farmers in remote locations move away from farming or become more risk averse where farm investment is concerned (Tanaka and Munro, 2014). According to this study, individual personal attitudes had less influence than subjective norms and perceived behavioural control for intentions on decisions about farm management. The effects of other personal factors, such as education level, gender and age, on management decisions did not appear clearly in the analysis. This was primarily because this study's methodological approach focused on decision-making at household level, rather than decisions made by individuals, and information gathering concentrated on the households in the study area. Cost remains the biggest external control factor for those farmers in the study area who are seeking to change their farm practice. As shown in Table 7-3, cost was the dominant reason for limited use of pure hybrid maize varieties. Opportunities to access these technologies at reduced cost, with microfinance options and improved crop insurance, could enhance agricultural adaptation to future impacts of climate change and variability (IPCC, 2014).

7.4.2. Using indigenous knowledge of soil and climate for land management

Environmental factors, in particular the combination of soil properties and rain, were found to affect farmers' decision-making on the use of manure, timing of seeding and crop choices. These indigenous knowledges about type of soils and rainfall led to good decisions for crop yield because they maximised the use of plant available water. In less fertile sandy soils, putting the manure into the hole with the seed retained enough moisture for germination, making targeted use of a limited resource exactly where it was needed. This was supplemented by the selection of new or traditional crop types and varieties, that were more tolerant of drought or a low nutrient content, for low fertility soils. These decisions were influenced by Kitui farmers' own evaluation of soil fertility, using indicators of texture and colour that showed a significant correlation with quantitative measures of the soil's nutrient status and water holding capacity (see Chapter 4). The timing of seeding is affected by the physical condition and workability of a specific soil and this is controlled by moisture content. Better and more meaningful rural communication services might help farmers adjust perceived behavioural control by following up failure experiences, trialling more innovative crop and soil management strategies, and changing local social norms.

Farmers focused on intra-seasonal climate variability, such as the adoption of drought tolerant maize for the short rain season. Farmer' narratives have been reported to show a decline in rainfall and in soil fertility in the area (see Chapter 4). Spreading risk through planting a mixture of crop types and varieties was also common practice, but this also related the different crops to niched needs or sequenced development. While dry planting was previously introduced in the area, experiences of failure resulting from highly variable starts to the seasons had become perceived behavioural controls and many farmers reported distrust in weather forecasts or refusal to plant early and diversify out of farming. Continued investment in early warning weather systems and meaningful communications of short-term variability is needed in Kenya to enhance longer term risk management and help farmers rethink perceived behavioural controls (Dorward et al., 2019).

7.4.3. Combining knowledges for future rural communication services

Communication of indigenous knowledge about agriculture was found to pass via family and friendship networks or through casual labour on neighbouring farms. The strength of the communication increased as distances between the participants grew shorter; it flourished when there was a strong relationship with the information source, and reflected a reliance on bonded networks. Farmers viewed the results of innovations (e.g. changes to manure use or a new crop variety) on these neighbouring fields, and could adopt them later with confidence. During daily conversation, farmers used bonded social networks to exchange knowledge about farm management, resulting in very good opportunities to acquire new information and experience follow-up. This reinforces the importance to agricultural innovation of supporting local social networks (Jackson et al., 2006). These mechanisms were not only used for locally developed knowledge but also to share information from outside the community. Although the majority of farmers had no direct communication with extension officers, they accessed new external knowledge by observation of pioneer neighbours' fields (e.g. comment from V1_19 in 7.3.4). However, it was found that reliance on this knowledge-sharing approach meant that failed experiments were seen as negative innovations, creating a perception that external knowledge was too risky (e.g. seeding before rain, see Table 7-4 and the negative experience of chemical fertilizer in Machakos in section 7.5). This has previously been explained in the literature as a dissonance between local and scientific knowledge systems (Ramisch, 2014). Learning from experience structured farmers' knowledge, but experiences of failure resulting from external information reinforced negative perceived behavioural control and had made it more difficult for households to accept risk or to innovate. Using the three conceptually independent determinants of intention within TPB as a lens through which to view how indigenous knowledge is shaped, reinforced and adjusted has been useful and has highlighted entry points to enhance or reduce farmers' motivation for good soil management. These insights help in rethinking the ways rural communication services may engage with different actors responsible for land management, and recognise the various ways in which knowledges can be understood. This chapter revealed the problem of neglecting farmers' failure after trying new methods and the importance of subsequent follow-up after that.

For example, the research found that weaker communication between farmers and extension officers equated to lower levels of adoption of new technology (e.g. chemical fertilizer). The introduction of innovations required trust and thus local social networks were more influential at stimulating adoption, even if these were not optimal. There is a strong demand among farmers for access to scientific explanations of the failure of innovations; more regular opportunities for farmers to ask questions could enhance the sustainable adaptation of agricultural innovation. This might require the rethinking of the engagement formats, such as the use of mobile platforms or community radio, including two-way communication (Achora et al., 2018; Mwangi et al., 2018). Only limited success in creating more meaningful interaction and developing hybrid knowledge (or co-produced knowledge) that meets local needs was found. For example, the introduction of a drought tolerant maize variety was relatively common in both areas and the application of manure in holes was popular in Village 1. Both had been adopted as a result of local information about scientific innovation, and have addressed local food insecurity. Increasing the number of successful experiences and positive perceived behavioural control is an important way to increase farmers' motivation to adopt new strategies in farm management.

This research has revealed two key routes for knowledge sharing for agricultural extension. Firstly, long-term relationships and trust built up over time between farmers and local extension workers have enabled better understanding of farmers' needs. Secondly, peer-to-peer networks for sharing information were highly valued by farmers. Combining both approaches within the local extension system would increase the effectiveness of the communication channels that have already been initiated by agricultural extension (e.g. Farmer Field Schools in Kenya (Ongachi et al., 2018) and farmers' research groups (Alemu et al., 2016), through which farmers are able to learn how to identify problems in their fields. Follow-up of failures creates future successes. This approach connects extension officers to farmers and their 'know-how' and 'practical knowledge' (Ingram, 2008). Access to technical information would provide farmers with deeper understanding of soil processes and increase their confidence in continuing to experiment with technologies that have previously failed because they were not fully adapted to the local context. Farmers expressed the need for more accurate early warning weather systems that would inspire greater confidence and support local adaptation to drought (IPCC, 2014): initiatives are now providing context-related options (e.g. PICSA, Clarkson et al 2019) that help farmers to plan for the season, using climate information and extension support on cropping. While it is challenging to ensure frequency of communication between farmers and extension officers due to limited national budgets (Umar et al., 2015), there are future plans to place more emphasis on face-to-face communication in isolated areas and increase the frequency of exposure to new information and follow-up through the use of apps, ICTs and farmers' peer-to-peer networks in Farmer Field School (FFS), which form part of the national policy of agricultural extension (Achora et al., 2018; FAO, 2017; Ongachi et al., 2018) in other parts of Kenya. Those pioneer farmers who can engage with this process have a greater opportunity to share their success stories and follow-up with new farmers, reinforcing personal confidence and the benefits of sustainable soil management.

7.5. Conclusion

This chapter revealed that, in Kitui County, Kenya, the farmers' differing economic situations made them adopt different strategies for soil management, with different motivations. Farmers with more stable incomes could try new technologies: previous success enabled them to trust the extension officers. Other farmers, who had limited opportunities to generate cash income and limited access to extension officers, preferred minimum investment and utilization of available land and livestock manure. The distance from town centres had a profound effect on the typology of livelihood diversification. However, overall, the farmers' peer-to-peer network acted as a strong information source and affected their motivation. As determinants of intention in TPB, subjective norms arising from communities' customs and perceived behavioural control based on experiences of success and failure strongly affected on farmers' decision-making. A hybrid communication approach, involving targeted extension services for isolated areas with follow-up to reduce negative opinions of innovations, utilization of ICTs and FFS, early warning weather systems which increase the farmers' trust in weather forecasts, and adding plans to deal promptly with climate extremes to current countermeasure could provide better understanding, information availability and management options for all households. The hybrid communication approach enables farmers to improve and sustain their soil management, and thus their rural livelihoods, in a climate change situation.

8. Conclusion

8.1. Introduction

This research sought to reveal farmers' knowledge of soil fertility, and the relationship with soil science knowledge and farmers' utilization of their knowledge for decision-making about soil management. Better understanding of these connections is important because it helps to show how to build hybrid communication approaches and hybrid knowledge systems that can lead to sustainable soil management under climate change. The research reveals the difference between farmers' and soil scientific knowledges and opportunities for enhancing communication among different types of stakeholders. To respond to the challenge, the research adopted an interdisciplinary research approach and a case study design that allowed a focused, in depth exploration of soil science knowledge among Kenyan farmers' through their perceptions of soil fertility.

For the aim to understand how the construction of farmers' knowledge of soil fertility compares to soil scientific knowledge and how the farmers' knowledge system is used for land management, The research was structured around three objectives intended to explain (1) the similarities and differences between farmers' qualitative evaluation and soil science quantitative analysis for soil fertility classification; (2) farmers' and scientists' knowledge of soil fertility and their understanding of the relationship between soil properties and processes, using mental models as a tool for understanding and communicating their soil knowledge; (3) how cropping and land management responses to climate variability and soil type are shaped by perception of risk, individual motivation and perceived capacity.

The following sections summarise the main findings for each objective by providing answers to each arising question, and offer reflections on the importance of these findings, as well as their methodological and conceptual contributions. The final two sections offer reflections on the implications of the results for policy and practice and further research questions that have emerged from this study.

8.2. Summary of key findings

8.2.1. Objective 1: To examine the similarities and differences between farmers' qualitative evaluation and soil science quantitative analysis for soil fertility classification

What are the similarities and differences between farmers' qualitative evaluation and soil science quantitative analysis of soil fertility and soil classification?

- Farmers in Kitui used a local soil classification system, applying indigenous knowledge and evaluation processes to their observations of structure and experiences of functions to assess soil fertility. It was found that 13 soil quality indicators were used across the 60 farmers interviewed (4.3.1). Five local soil classifications were used by farmers within the study area (4.3.3). Across all farmers, the most consistent indicators used for the evaluation of 'good' soil fertility were texture and colour, while texture alone was used for 'poor' soil fertility (4.3.1). Texture and colour are both key soil quality indicators used by soil scientists.

- There were statistically significant relationships between farmers' classifications of soil texture and colour and more detailed laboratory physicochemical analysis (4.3.5), revealing synergies between the two knowledge systems. Soil texture properties were key drivers of soil fertility in Kitui, indicating the importance of nutrient and water limitation. Soil colour was used for identification of clay minerals by farmers. This is consistent with the literature (Murage et al., 2000; Mairura et al., 2007), which considers high WHC to be a driver of soil fertility under semi-arid climate conditions.

- Farmers used holistic information of farming experiences, historical social and environmental narratives, a detailed knowledge of the landscape and spatial scale to shape their soil knowledge. Their daily experience and observations were used to construct soil fertility indicators, such as the workability of soils (4.3.1) or social and environmental changes in local history that have reduced the amount of black soil and other soil types with less organic matter seen on the surface from subsoil (4.3.6).

How does the location of soils (e.g. villages and distance from home) influence farmers' evaluation of soil fertility?

- Land near to the family homestead or the river was predominately evaluated by farmers as the most fertile soil. Water from home waste or rivers was perceived to supply both nutrients and water to the soils continuously (4.3.2).

- Between the two study villages, there were differences in use of English terminology and availability of each soil type. The English terminology reflected the absorption of external knowledge through extension and schools in Village 1, which is near a town (4.3.3). The existence of a larger quantity of black clay soil near the river in Village 2 implied better land availability and the ability to own a greater number of fields in Village 2, which is far from the town (4.3.2).

Overall, farmers in Kitui mainly used soil texture and colour for their soil fertility indicators, which were also the major indicators used in soil science. Farmers' classification of texture and colour had a significant correlation with scientific measures of soil nutrient status and water holding capacity. The two indicators of texture and colour were used as the starting points for the creation of a local tailor-made soil assessment system, that also integrated farmer and soil science knowledges. The local evaluation reflected the historical context, including settlement and organic topsoil loss, and the farmers' perception of scale and specific location. These backgrounds of indigenous knowledge should be involved in effective knowledge exchange.

8.2.2. Objective 2: To explore farmers' and scientists' mental models of soil fertility and the relationship between soil properties and processes for communicating soil knowledge

Is it possible to create mental models of soil fertility, within a mixed cropping and livestock farming system with a semi-arid climate, for farmers and scientists by considering what makes soils fertile?

- Three different mental models (fertile soil by farmers, low fertility soil by farmers and fertile soil by soil scientists) were created separately in chapter 5 and 6. Three thematic areas emerged to characterise Kitui farmers' perceptions of soil fertility: soil management, soil property and specific location (5.3.1-2).
- Farmers precepted fertile soils mainly from high WHC from clayey texture and location near water source and adding manure and fertilizer as nutrient source. Only low WHC from coarse texture (sandy and stony) was emphasized as key concepts of low fertility soils (5.3.1-2).
- Scientists who had conducted research experiments in East Africa described the components of soil fertility according to standard soil science categorizations using physical, chemical and biological properties and soil formation factors, adding the importance of management (6.3).

What are the differences in knowledge of soil fertility among farmers?

- There were differences between farmers in their knowledge about the relationships between soil processes and property. Some farmers were able to articulate a relationship between texture and water, through drainage, wet soils and plant rooting systems, demonstrating an understanding of the relationship between soil properties and processes of plant growth. By contrast, the connection between decomposition of organic matter and nutrient release and organic matter and water availability was rarely explained by farmers. The rate of answers in each mental model also shows the difference for each farmer's soil knowledge.

- The location-based differences between the two study villages were shown; farmers near the town emphasized the importance of adding inputs to soil, reflecting availability of soil management information from extension and a more intensive farming system, while farmers in the remote locations focused on water availability, reflecting the greater availability of land with better fertility soil and an extensive farming system.

What are the synergies and differences between farmers' and soil scientists' mental models of soil fertility?

- Kitui farmers and the soil scientists saw WHC and management for soil fertility as the most important concepts (Figure 5-1, Figure 5-2, Figure 6-1). However, they connected soil texture directly to WHC, and the relationships of soil properties and soil process was not well understood by most farmers. The importance of OM and soil structure was not mentioned by farmers, even though soil scientists considered it a major factor in water retention and nutrient supply for plant growth. The information from the specific location, including farmers' experiences and observations of field management and the history of social and environmental changes, was not prioritised in the soil scientists' mental model.

The methodological approach of creating mental models of soil fertility for Kitui farmers and soil scientists helped to reveal the differences in knowledge construction and demonstrate how these could be visualized and compared. The approach revealed useful entry points for enhanced two-way communication between farmers and extensionists schooled in soil science. For example, both the mental models of fertile soil identified the importance of WHC and management and would be a starting point for the provision of new information and discussion platforms. The soil scientists' mental model provides a visual learning material for farmers to help to improve their understanding of the integrated relationships between soil properties and processes. The farmers' mental model is a good reference, helping people engaged in academic surveys, extension work and development projects to understand site-specific indigenous perceptions of soil fertility and enhance co-developed solutions to soil fertility challenges.

8.2.3. Objective 3: To explore how cropping and land management responses to climate variability and soil type are shaped by perception of risk, individual motivation and perceived capacity.

What are the dominant livelihood strategies and farming systems for different farming household?

- There were three main livelihood strategies identified in the study area: specialization in off-farm income (Cluster 1), fruit and vegetable farming (Cluster 2), and a combination of off-farm and mixed farming (Cluster 3 and 4) (7.3.1). The livelihood strategies are affected by the location of the villages studied: Cluster 1 and 2 are occupied by farmers from Village 1 near the town, and Cluster 3 and 4 are dominated by farmers in Village 2, in a remote area.
- Clusters 1 and 2 showed more ability to integrate external knowledge; they had stable incomes and more trust in information from extension officers. In Clusters 3 and 4, minimum investment was the farmers' priority with more land availability. The differences appeared clearly in their selection of maize varieties and use of chemical fertilizer (7.3.3).
- According to the determinants of intention in TPB, the promotion of new knowledge (e.g. about chemical fertilizer) became a local subjective norm and the positive and negative effect of promotion resulted in the adoption and rejection. In addition, previous experiences of success and failure became perceived behaviour control of farmers' decision-making. Self-confidence and trust of an information source enhance the use of chemical fertilizer and dry planting. (7.3.3).

How does intra-annual climate variability change these narratives, for example, under drought or wetter conditions?

- All sampled farmers adapted crop cultivation to long and short rain seasons, and fertile and low fertility soils, to manage inter-annual climate variability. For example, the combination of soil properties and water from rain affected the use of manure, timing of seeding and crop choices (7.3.3); the soil fertility affected on manure use, the workability of soil with moisture level affected on the timing of seeding and the water capacity of soil affected on the crop selection (7.3.3).

- Inter-annual climate variability was recognized by farmers because after drought chemical use was reduced to reduce economic losses (7.3.5). Timely countermeasures (e.g. changing maize varieties) were predominantly a response by farmers who had close relationships with local extension officers and access to advice or seeds, and a few poor farmers who had high motivation to experiment. The effect of different livelihood strategies was also shown under climate change situations, as in the sensitive care given to their crops by Cluster 2, whose incomes came mainly from selling fruit and vegetables. Excessive rain was recognised as less of a risk by farmers who combined off-farm and mixed farming (Cluster 3 and 4) in a semi-arid climate.

How do information sources and communication with extension officers and among farmers affected for changing farmers' soil management pattern?

- Farmers in Cluster 1 and 3 had more communication with extension officers from past and trusted and adapted new innovations (e.g. chemical fertilizer and dry planting) and more than that in Cluster 3 and 4 (7.3.5).

- Due to the limitation of current extension services, communication among farmers had strong power for their decision-making (7.3.5), especially the rejection of chemical fertilizer usage by farmers in Cluster 3 and 4 (7.3.3).

- For drought, farmers felt they faced uncertainty because they did not trust local weather forecasts, which often led to no change in management during climate extremes (7.3.5).

The livelihood strategies and locations of the villages affected the differences between farmers' soil management decisions. Soil types and water availability affected the workability of fields, the priority of cash-crops and the timing of seeding. The difference in management between farmers was a result of previous experience and the level of trust in information sources, such as the extension services and farmers' peer-to-peer communication. With the problem of national cost-cutting for extension services and the growing impacts of climate change, it is important to draw on these insights to improve extension approaches. For example, the development of hybrid communication approaches involving targeted face-to-face extension, utilization of ICTs and FFS, and a clearer early warning weather system, would enhance the level of trust between farmers and extension officers, and focus on co-development of local solutions and support for local experimentation. The hybrid knowledge emerging from the new communication approach would increase each household's capacity for adapting climate change.

8.2.4. Revisiting the conceptual framework

Reflecting on the conceptual framework of this thesis (Figure 2-6) based on the use of indigenous knowledge systems, these key findings filled the research gaps and achieve the aim of this study to understand how the construction of farmers' knowledge of soil fertility compares to soil scientific knowledge and how the farmers' knowledge system is used for land management::

1) There was significant correlation between farmers' qualitative soil fertility evaluation and soil science quantitative analysis of soil samples from farmers' fields. Availability of different soil types in each location and local historical change affected the construction of indigenous evaluation of soil fertility and created site-specific knowledge.

2) Farmers' mental models visualises local perceptions of soil fertility and showed how it was dominated by the WHC of soil in a semi-arid climate. The improvement of soil fertility by adding soil amendments was more important for farmers who suffered from limited access to land and often those using a more intensive farming system as a result. While farmers understood soil properties, soil processes were rarely mentioned. This was the main difference between the farmers' and the soil scientists' mental models.

3) The linkage of Kitui farmers' communication and decision-making was revealed. At the communication stage, the farmers' peer-to-peer communication had a stronger effect on the creation of farmers' experimental knowledge than the current limited extension services had on their management. This was true of both villages, even though more information from extension officers was accumulated in Village 1, near the town, than in Village 2, in a remote area. At the decision-making stage, the locational inequality of information and land become one of the major external factors. Difference in livelihoods, including income and land tenure, was a major internal factor (capacity). Availability of reliable information and previous experiences of failure and success affected farmers' confidence in the adoption of new technologies and became another major internal factor (attitude) influencing their decisions to try more innovations. Soil types and fertility of each field influenced as another external factor for crop selection and timing of planting based on WHC, workability and nutrient status. Drought was the other external factor that affected some farmers, mainly those who earned income from fruit and vegetables, but the effect was still limited distrust of current weather forecasts. The development of a hybrid communication approach including an early warning weather system would be a key one-time countermeasure for climate extremes.

8.3. Implications for policy and practice

Throughout this thesis, the importance of communication among stakeholders for the creation of hybrid knowledge of soil fertility management has been argued. The definition of hybrid knowledge in this study is "Knowledge generated through a process that facilitates the integration of local (indigenous) and technical (scientific) knowledge" (Barrios and Coutinho, 2012: 66). According to the argument by Black (2000), hybrid knowledge is essential to deal with new environmental problems including climate change which need site-specific countermeasures. Some good examples of the use of hybrid knowledge for adapting climate change were shown in the data from the study site, such as the introduction of hybrid maize varieties in their traditional mixed cropping and putting manure into seed holes to keep moisture for germination (see Chapter 6).

For further development of hybrid knowledge, the development of a hybrid communication approach has also been required, to increase the opportunity for the creation of new knowledge thorough communication at various levels by different stakeholders, enabling them to share core concepts and fill knowledge gaps (Figure 2-2). The implementation of the results of this study at local, national and global level was suggested. These suggestions will contribute to the development of new communication strategies in agricultural development projects and a new national extension policy to increase farmers' ability to adopt suitable innovations for sustainable soil management.

Local: Improvement of communication between farmers, extension officers and soil scientists

The farmers in the areas where there was more communication with extension officers have adapted more hybrid techniques. The improvement of two-way communication between farmers and soil scientists, and between farmers and extension officers, give further opportunity for creating hybrid knowledge, which could become a basis for the development of integrated soil management approaches. Farmers demonstrated clear 'know-how (Ingram, 2008) with rich knowledge of soil properties associated with good production. Yet more could be done to improve sharing of information about soil processes or 'know-why' (Ingram, 2008), with farmers to support deeper understanding of the link between soil properties and processes. Communication with farmers needs to be within a more holistic framework with space for validation or feedback on language, tools and practice, to improve genuine two-way communication and facilitate social learning (Jackson et al., 2006; Smith et al., 2015). A visual learning material based on soil scientists' mental model improve farmers' understanding of soil properties and processes and the farmers' mental model is a good reference to understand site-specific indigenous perceptions of soil fertility. These kinds of knowledge brokering would generate a new, hybrid knowledge among farmers, extension officers and soil scientists.

Building on this understanding, creating a tailor-made soil assessment system, which reflects regional characteristics of local soil knowledge, would enhance two-way communication. Each region has its own indigenous knowledge of soils, and including regionality in the key soil indicators. The system would increase farmers' willingness to learn about the scientific aspects of soil and strengthen their motivation for applying their implications to management. In addition to the processes of learning from farmers' experience, adding scientific or technical follow-up after the harvest accelerate the integration of local and external knowledge and the creation of hybrid knowledge. The farmers know the holistic information of their fields, and if extension officers apply this information when they follow up the farmers' failures, it becomes a step to the next success and don't become a negative rumour.

National: Development of national policy for extension services

A national policy is needed for the implementation of practices at the local level. The current limits on the budget and human resources for extension reduce the opportunity of face-to-face communication between farmers and extension officers. However, the development of a participatory hybrid communication system, involving Farmers Field School (FFS) (Davis, 2006), with the collaboration of information and communication technologies such as the utilization of phone, SMS and mobile applications for agricultural extension, would be a good solution. If the limited extension officers' visits focus on the remote areas in order to create trustful relationships, inequality across extension services would be reduced. FFS currently has some problems: it does not lead to quick or wide extension outcomes (Braun and Duveskog, 2009) and finds it difficult to maintain on financial sustainability (Davis, 2006). However, including FFS into a package of extension programmes involving the use of visual materials (e.g. Video-mediated farmer-to-farmer learning, Mele, 2011) would increase the sustainability of the FFS and farmers' understanding of scientific knowledge. For example, the Soil Doctors Programme, a farmer-to-farmer training programme, has been active in Thailand and has enhanced the awareness of soil knowledge and sustainable management practices in remote areas (Omyamyen et al., 2007). The programme has also developed a mobile application to introduce the best practices for each soil types by connecting with a national soil map. Building farmers' capacity to understand soil processes and the connections between texture, colour, organic matter and water would be needed to facilitate improved soil water management. This example could be adapted and applied to Kenya.

Financial support by subsidy, micro-finance or insurance for trying or adopting new technologies would also reduce the farmers' insecurity. The use of smartphones for remote extension services is being started in the research area (an officer of the Ministry of Agriculture explained about the pilot project). This has been a new trend in extension services: for example, the trial of the "plantix" app in Plantwise project by CARI was started in 2018. The feedback from farmers using new services is also a good source of local information that can be used to create hybrid knowledge and tools to build better understanding of local conditions.

Distrust of weather forecasts leads farmers to believe that drought could happen at any time, and as a consequence they have adopted practices to deal with drought every year. The development and utilization of accurate early warning weather systems in Kenya would improve the farmers' risk management, and reduce perceptions of risk, possibly enhancing investment and experimentation.

Global: Implementation of SDGs

These suggestions for local and national level could be relevant to different locations where problems arise from miscommunication between farmers and soil scientists or extension officers. The development of a hybrid communication approach for sustainable soil management under climate change would contributes the achievement of the following SDGs: Goal 2 "Zero hunger", Goal 13 "Climate Action", and Goal 15 "Life and Land". Improvement of soil fertility using improved communication with farmers, and the creation of co-designed tools and solutions, will increase local food availability where there are distribution problems and will foster resilience to climate change.

A nutritious soil creates nutritious foods. Nutrition improvement is one of the main issues addressed by SDGs Goal 2, and the Initiative for Food and Nutrition Security in Africa (IFNA), which was established in 2015. The importance of soil productivity for supporting nutrition in climate change conditions was also mentioned by Mars, Heineken and Olam in the 2018 IFC Agribusiness Conference.

For the implementation of activities at local and national levels, the establishment of global standards and support is required. Building on the success of the Soil Doctors Programme in Thailand, the FAO is launching the Soil Doctors Global Programme, in which I am taking part as an intern and a Personal Service Agreement with the Global Soil Partnership (GSP). The utilization of mobile devices has been included in new e-agriculture programmes, creating investment for innovation by many international organizations, including FAO and the World Bank. The further effort to the creation of global system to integrate indigenous knowledge to the innovation is the next step.

8.4. Future research

Three potential research areas have evolved from this study: Differences in farmers' knowledge caused by differences in ethnic groups, location and other personal factors, impacts of different management on soil fertility and

Differences in farmers' knowledge caused by differences in ethnic groups, location and other personal factors

This research used a case study approach and local taxonomy, indicators and mental models for soil fertility are of one specific county context. Farmers' knowledge of soil is constructed holistically, based on their experience and local environment (Barrera-Bassols and Zinck, 2003), so farmers' perception of fertile soils may be different in other areas with different environments or soil conditions. Further work is needed to compare farmers' soil knowledge across different regions and climatic zones, in order to study the differences among farmers working in different locations and environments. The data gathered from other regions may help to reveal fundamental features of farmers' knowledge, contributing to the creation of global standards for the utilization of indigenous knowledge in sustainable soil management. Undertaking cooperative research with anthropologists and geographers would expand the contents of ethnopedology.

The effects of personal factors, such as education level, gender and age on management decisions were not considered in detail in the analysis presented here. Based on the results, individual personal attitude was less important than subjective norms and perceived behavioural control for intentions on decision-making about farm management. This was primarily because the study's methodological approach focused on decision-making at household level, rather than by individuals, and the collection of information in the study area concentrated on households. Gender is one of main factor of the inequality of extension, gender difference was not explored throughout this study. Further research should focus on the roles of gender and individuals in a household, to provide additional reflections on the effects of personal attitude and status on decision-making.

Impacts of different management on soil fertility

Although the influence of soil properties to and from management argued in thesis, no quantitative analysis of the effects of management alone could be provided, because of the complexity of the factors affecting soil fertility. The quantification of the effect of farmers' actual management would reinforce the importance of human activity as a soil formation factor. This could be studied further, through interdisciplinary work between farmers, scientists and social scientists, constructing meaningful field trials with systematic programmes of experimentation and observation.

Explore scientists' and farmers' perceptions for the use of farmers' indigenous knowledge and how this can help to create hybrid knowledge to deliver SDGs

This thesis reveals the importance of communication of knowledge and collaboration in its construction. The next step is to act on its implications. The creation of hybrid knowledge and evaluation in the fields of academic research and actual practice in development programmes increases the amount of data available for the creation of other forms of hybrid knowledge necessary for the delivery of SDGs. In addition to increase awareness of social scientific studies of soil by publishing more articles in scientific journals (e.g. Prager and Curfs, 2016, Soil Use and Management), Involving more soil scientists in the study as actors of sustainable soil management and getting feedbacks about the comparison of farmers and soil scientific knowledge (e.g. by using mental models) connect to build suitable processes for a new communication approach. The feedback from farmers is also important. The feedbacks from both sides will accelerate filling gaps of knowledge and increase space for the creation of new hybrid knowledge.

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Appendix
Appendix 1: A published paper based on Chapter 4

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

Yoshie Yageta[a,*], Henny Osbahr[a], Yasuyuki Morimoto[b], Joanna Clark[c]

[a] *School of Agriculture, Policy and Development, University of Reading, UK*
[b] *Kenya Country Office, Bioversity International, Kenya*
[c] *Department of Geography and Environmental Science, University of Reading, UK*

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ABSTRACT

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

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

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 et al., 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

* Corresponding author at: School of Agriculture, Policy and Development, University of Reading, Whiteknights, PO Box 237, Reading RG6 6AR, UK.
E-mail address: y.yageta@pgr.reading.ac.uk (Y. Yageta).

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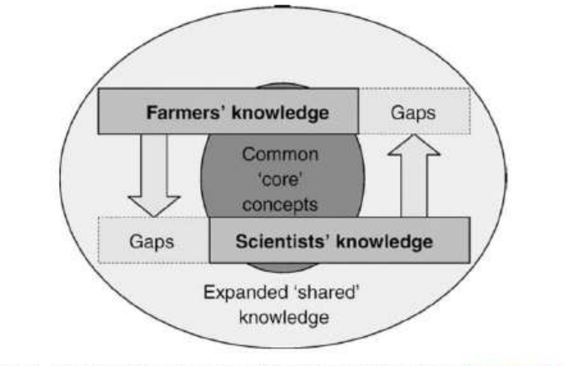

Fig. 1. Conceptualising an expanded shared knowledge system (Barrios et al., 2006).

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' (p. 236 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 (Fig. 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; pp. 125–126) argued that "while many traditional problems may be solved with new methods, new problems, particularly environmental problems, may be best dealt with through a combination of new and traditional extension."

The starting point of soil fertility evaluation by farmers and soil scientists are same: the performance of crop growth (Vilenskii, 1957; Murage et al., 2000). In addition, farmers also explain the characteristics of fertile or non-fertile soils, mainly by visual and morphological features, such as texture and colour which was used as universal criteria of soil fertility (Mairura et al., 2007 in Central Kenya; Kamidohzono et al., 2002 in West Sumatra). Even from the same starting point, the direction of interests is different. Soil scientists measure soil as a natural resource using quantitative analysis, while farmers evaluate soils as part of their daily experience in the field (Ingram et al., 2010). Farmers have more 'know-how' or 'practical knowledge' about soil, and scientists have more scientific knowledge or 'know-why' about soil (Ingram, 2008). These differences can be categorized into three main parts: perception of other environmental information; spatial scale; and timescale.

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

Second, farmers' evaluation focuses on a smaller scale, related to farm, field and within-field plots, reflecting subtle understandings of soil diversity. Many studies have shown that local soil classification is more detailed than international soil classification (Barrera-Bassols and Zinck, 2003; Osbahr and Allan, 2003). It may be argued that farmers are able to evaluate soils in suitable ways for their farm management and soil scientists are able to generalize sample data to explain underlying patterns across landscapes and make maps. Of course, detailed local knowledge has the limitation of site specificity (Cook et al., 1998) and scientific soil classification or mapping can provide insights at regional, national and global scales. While the main reason for soil classification or mapping is use for planning of soil conservation and soil management improvement to lead to better plant growth, original baseline data for the classification of soils were generated by soil survey, topographic and geological mapping which relates to pedology and a focus on soil formation (Brady & Weil 2016). Originally, soil maps were designed to deliver information for managing landscapes and to create a common language of soils, with underlying general principles that explain complexity. Generalizations were necessary at landscape scale (Ashman and Puri, 2008) and thus the scale for farmer and science knowledge systems deviates.

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

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

2. Approach and method

2.1. The role of the case study approach

The research approach adopted was to use an illustrative case study that enables capture of detailed local level understanding and to incorporate people (Yin, 2013), which may not be possible in a large scale soil study (Wilbanks and Kates, 1999). Kenya was selected because it is illustrative of a sub-Saharan developing country where agriculture

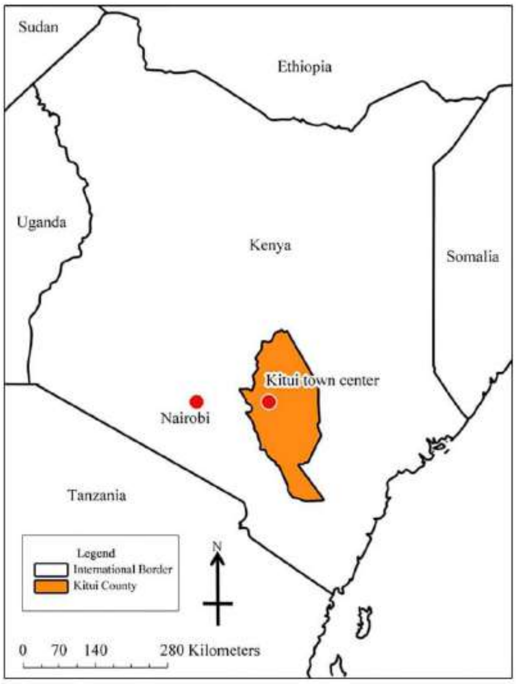

Fig. 2. Location of Kitui County within Kenya.
Modified from County Government of Kitui (2013).

dominates the national economy (Wambugu et al., 2011) with > 70% of the population relying on small scale farming (Republic of Kenya, 2014).

Within Kenya, the research focused on Kitui County, located about 170 km east of Nairobi (Fig. 2). The first rationale for selecting this county is the identification of contrasting soil types as recorded on the soil map for the region, resulting from the metamorphic bedrock and variation of slope (Mine and Geological Department Kenya colony North-West Quadrant, 1954; Sombroek et al., 1980). The area has a semi-arid climate, with temperature between 14 °C to 34 °C, and two rainy seasons: 'long' from March to May and 'short' from October to December approximately (County Government of Kitui, 2014). The exact period and amount of rain is erratic and unpredictable from year to year, with annual rainfall between 250 mm and 1050 mm (County Government of Kitui, 2013). The major ethno-cultural group is the Kamba, and KiKamba is spoken by most people in Kitui County (KICABA Cultural Center, 2013). The Kamba have practiced livestock rearing, hunting and farming for centuries, introducing rhizome and pulse cultivation from the 17th Century (Ikeno, 1989). The population living and farming on marginal lands have increased since the 20th Century when many Kamba moved from neighbouring Machakos to move from poor soils with high rates of degradation (Ikeno, 1989; Karanja et al., 2017). Today, 87% of residents earn their livelihoods from agriculture using an average 2 ha farm, with additional income from salary, casual local labouring and migrant work (County Government of Kitui, 2013). Both mixed and monoculture rainfed farming is practiced with maize, legumes, green grams, cowpea and pigeon pea as the main crops. Small numbers of livestock are owned and the manure is used to fertilise the fields, although the amount is limited. The use of chemical fertilizer is low due to the cost (Ralph et al., 2006; County Government of Kitui, 2013). The second rationale for selection was the deep cultural rural farming knowledge and that a traditional land use system is practiced, similar to other parts of Kenya. This land use system includes three types of enterprise areas: out-fields (away field), in-fields (home garden) and a home site (kitchen gardens) (Woomer et al., 1998).

Within Kitui County, two villages were selected using purposive sampling (Tongco, 2007) to evaluate the effect of the difference of location for soil knowledge. Four criteria were used: (a) location in the same soil type based on the national soil map and in same Agro-Ecological Zone (AEZ); (b) a majority of villagers as small scale farmers; (c) no active NGO activity or agricultural extension projects; (d) different distances from Kitui town centre and different frequency of communication with extension workers (one higher than the other). Soil types indicate soil general properties so they are assumed to affect farmers' perception of soils and fertility, and AEZ represents the climate condition of the area. Therefore, it was important to take data from the same high-level soil type and AEZ to reduce excessive variation of natural factors and focus on variation from social and management factors. The distance from town centre can affect the level of extension service, and therefore, access to scientific knowledge (Anderson, 2006). A national soil map, AEZ map (Sombroek et al., 1980), and road map (WFP, 2007) of Kenya were processed on ArcGIS to identify the potential area and then shown on Google Earth. The national soil map (Sombroek et al., 1980) identifies the study area as Um19; 'well drained, moderately deep to deep, dark reddish brown to dark yellowish brown, friable to firm, sandy clay to clay; in many place with top soils of loamy sand to sandy loam (ferralo-chromic/orthic/ferric ACRISOLS; with LUVISOLS and FERRALSOLS)' (p. 25). Acrisols and Luvisols are determined by the existence of Argic horizon (accumulation of clay) and classified by CEC ($< 24\ cmol_c\ kg^{-1}$ is for Acrisols and $> 24\ cmol_c\ kg^{-1}$ is for Luvisols) and base saturation (< 50% for both) (IUSS Working Group WRB, 2015). Ferralsols are determined by a red colour and low activity clay minerals (IUSS Working Group WRB, 2015). The national soil map does not describe a finer level of soil differentiation. The bedrock is marked as area *Xg* on the Geological map for Kitui (Mine and Geological Department Kenya colony North-West Quadrant, 1954) and described as 'Microcline-oligoclase-biotite-hornblende migminte with biotite anplibolite schlieren granitic sheet and vien reticulation'.

Visits to villages to triangulate the soil data was conducted and, with support from Agricultural Extension, Village1 (Kavuti) and Village2 (Kitambasyee) were selected to represent locations with similar environmental conditions but different social conditions (Fig. 3). GPS data showed elevation was similar (1180 m in Village1 and 1000 m in Village2) and field slope were similar with flat to moderately steep (0

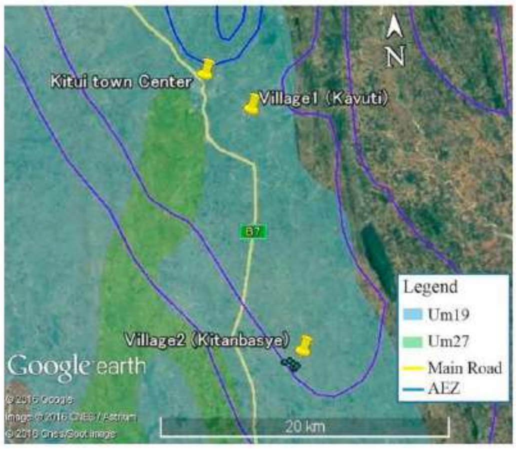

Fig. 3. Location of study site: the two study villages are located in same soil type (Um 19) in national soil map and same AEZ zone (marginal cotton zone (vs/s + s/vs)) (Google earth).

to 25%) (Soil Survey Division Staff, 2017). Village1 was located near Kitui town (4.5 km) with historically frequent communication from Agricultural Extension officials - the village was located near the chief's office and where public meetings are held, a Ministry of Agriculture official lived in the village, and some farmers had relatives or friends who engaged with volunteer extension activities. Village2 was located 20 km from the town, although due to limited transport it can take more than 2 h to walk, and there was limited communication with Agricultural Extension officials.

2.2. Data collection: farmer knowledge

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

2.3. Soil sampling and laboratory analysis

Soil samples were collected in August 2017 from the best and the worst fertile place in fields, as identified by each farmer. The sampling occurred just after harvest and the last short rains in fields that had not yet been prepared for next growing season. This was considered good timing for evaluating baseline soil nutrient status with minimal impact from additional inputs. Surface (10 cm) soil samples were taken from 10 points within each field and bulked to make single composite samples of 500 g. The total number of soil samples was 116, 59 from the best fertile locations and 57 from the worst fertile places. This was because four farmers had just one farm and one of them evaluated their field as not fertile only while another evaluated their fields as fertile only.

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

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

For the chemical parameters, pH in H_2O (1:2.5) was measured using a glass electrode pH meter (Carter and Gregorich, 2008) and electronical conductivity ($EC_{1:1}$) was measured using a conductivity meter (Richards, 1954). The Total Organic Carbon (TOC) was determined by the Walkley-Black method (Walkley, 1947), Kjedhal Method (Okalebo et al., 1993) was used for Total-Nitrogen (T-N), and Nitrate-Nitrogen (N-N) was extracted with 2.0 M KCL and measured by 0.01 N H_2SO_4 using an Auto-Titrator (Keeney and Nelson, 1982). Available Phosphorus (P) was measured by Mehlich 1 (Mehlich, 1953; Nelson et al., 1953), Exchangeable Potassium (K) and Sodium (Na) were extracted by ammonium acetate and measured using an atomic absorption spectrophotometer and Cation Exchange Capacity (CEC) was assessed with ammonium acetate after exchangeable cation extraction using the semi-micro distillation method (Lavkulich, 1981).

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

2.4. Data analysis

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

3. Results

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

3.1. Farmer knowledge: key soil properties used in farmers' evaluation of soil fertility

The characteristics of soils of the best and worst fertile places were described by farmer in response to an open question (Fig. 4). Texture was the primary soil property used by farmers to evaluate both best and

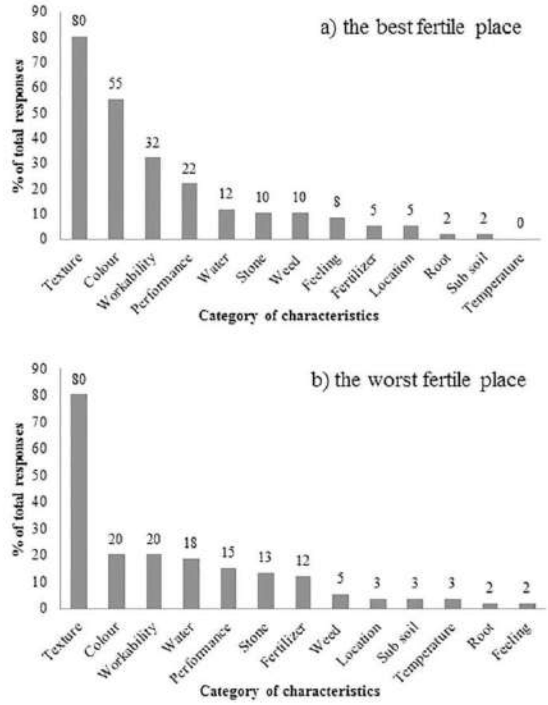

Fig. 4. Farmer indicators of soil fertility (a) indicators of best soil fertility place ($n = 59$), (b) indicators of worst soil fertility place ($n = 57$).

worst fertility. Colour was used to identify best fertility. There were other properties used by farmers, but these were less commonly used across the whole group. In total, 13 soil properties were identified as indicators for both best and worst soil fertility: texture, colour, workability, plant performance, water, stoniness, weed, feeling, fertilizer, location, root and sub-soil. Temperature was used only as an indicator for worst soil fertility.

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

3.2. Farmer knowledge: role of farm scale and location

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

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

3.3. Farmer knowledge: local terminology for soil fertility evaluation

Farmers considered the fertility of soils through the healthiness of the crops grown. This connection was reflected in the articulation of soil fertility, with healthy (fertile) and non-healthy (unfertile) terminology used. Farmers perceived a connection between the healthiness of soils, plants and people (e.g. between good soils and production, food security and nutrition), and articulated this relationship using visual terms or outcomes (e.g. 'an overweight person would have fertile soil and more to eat'). In KiKamba, soil is called *Mūthanga* and the word for fertile is *Mūnou* so good fertility soil is described as *Mūthanga Mūnou*. The word *Mūmosu* is used to describe a lack of fertility, and therefore poor soil fertility is *Mūthanga Mūmosu*. Interestingly, *Mūnou* and *Mūmosu* were also terms used for expressing human healthiness. A human being is called *Mūndū* in KiKamba, with *Mūndū Mūnou* used to refer to an overweight person, and often used to convey being healthy or having contentment. In contrast, *Mūndū Mūmosu* is used to refer to an unhealthy thinness or something lacking in the human body. Technical or science-based crop performance indicators were not used by farmers as the first terminology to describe soil fertility (Fig. 4) as farmers considered it necessary to reflect initially on the characteristics of *Mūthanga Mūnou* (or *Mūmosu*) and the collective healthiness of the soil and the crops.

Table 1 presents farmers' soil classification terms and how these relate to their designations of best and worst soil fertility on their farms. Farmers relied on 11 classifications, eight locally-defined terms and three defined in the English language. The eight locally-defined terms were divided into three groups: feature of soil; fertility classification; and formation type. There were five categories based on physical soil properties, including texture and colour, sandy soil (locally known as *Nthangathī*), black soil (*Mwiū*), red soil (*Mūtune*), stony soil (*Kīvuthī*) and black-clay soil found near rivers (*Īlimba*). Most answers were organised into these physical soil categories (91%) and KiKamba terminology was used for the majority of soil classification labels by farmers in Kitui.

Table 1
Local soil classifications, with associated soil fertility and texture terminology (source: individual interviews n = 116 sites, 30 farmers).

Local soil name	Meaning in English	No of samples	Fertility evaluation		Texture		
			Best	Worst	Clayey	Loamy	Sandy
Mūnou	Good soil	1	1	0	1	0	0
Kīvumbu	Sedimentary soil	1	1	0	1	0	0
Īlimba (Īlivī)	Black clay soil near river	12	12	0	6	6	0
Mwiū (+*Mūtune*, +*Nthangathī*)	Black soil	24	23	1	4	18	2
Mūtune (*Kītune*, *Ūtune*, +*Īlimba*, +*Nthangathī*)	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
Nthangathī (+*Mwiū*, +*Mūtune*)	Sandy soil	34	5	29	4	12	18
Kīvuthī (Kīthathai, Ūthathai, +*Mūtune*, +*Nthangathī*)	Stony soil	16	0	16	8	5	3
Yalata (Mwalata, Mwalata *Mwiū*)	Bad soil	4	0	4	2	2	0
White soil	–	1	0	1	0	0	1
Total		116	59	57	42	49	25

Although there were some synonyms and a few instances of mixes of category, it was still possible to consistently identify a dominant soil type with farmers. For example, in the category of *Mūtune* (red soil), there were two synonyms *Kītune* and *Ūtune* and a mix with *Īlimba* i.e. red soil with some black clay. Terminology for soil fertility can also be referred to as good (*Mūnou*) or bad (*Yalata*). There was just one category that reflected soil formation characteristics, which was a type of sedimentary soil called *Kīvumbu* (other meaning of *Kīvumbu* is clay soil found in termite mounds, personal communication with a local scientist). In addition to these local terms, three English terms were used to describe loam, clay and white soil.

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

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

Texture associated with each local soil classification was compared to scientific analysis of soil samples. The results of texture analysis made by a hand test were aggregated into three categories: clayey refers to clay dominated (> 35% clay), including clay, sandy clay and clay loam; loamy describes moderately sandy, including sandy clay loam and sandy loam; and sandy, which is sand dominated (> 75% sand), including loamy sand and sand. Clayey to loamy texture soil types were mainly classified from the best soil fertility locations, while course texture (sandy or stony) soils were classified from the worst soil fertility locations. *Kivuchi* and *Yalata* were classified as clayey to loamy texture using a hand test and those with significant stone content removed by sieving were classified as stony or course texture soils (Table 3).

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

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 *Mūnou* and *Kīvumbu* 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 and Geological Department Kenya Colony, 1954). Therefore, it can be implied low organic matter in the soil.

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

3.5. Relationships between farmer evaluation of soil fertility and soil physicochemical parameters

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

The difference in soil texture can be shown to be reflected in the values found in the physicochemical analysis (Table 4a). First,

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

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	
Mūnou								1				1
Kīvumbu							1					1
Īlimba (Īlivī)	1	3	2		6							12
Mwiū (+*Mūtune*, +*Nthangathī*)		1		1	14	2	5	1				24
Mūtune (*Kītune*, *Ūtune*, +*Īlimba*, +*Nthangathī*)					3	2	11	2		1		19
No name							1					1
Clay loam soil					1							1
Loam soil					2							2
Nthangathī (+*Mwiū*, +*Mūtune*)					16	13	5					34
Kīvuthī (Kīthathai, Ūthathai, +*Mūtune*, +*Nthangathī*)					7	2	4	2			1	16
Yalata (Mwalata, Mwalata *Mwiū*)					2	1	1					4
White soil									1			1
Total	1	4	2	1	51	20	28	6	1	1	1	116

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

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

3.6. Soil evaluation and historical narratives

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

With limited capacity for many farmers to practice intensive farming and maintain soil fertility, there are challenges for current soil fertility: "*The rain washes away the humus and top soils…after humus rich*

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	WH C%
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.

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

4. Discussion

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

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

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

(a)		Soil texture			P value
		Clayey (n = 42)	Loamy (n = 49)	Sandy (n = 25)	
Soil fertility evaluation	Best	24	30	5	0.002**
	Worst	18	19	20	
Village location	1	28	22	8	0.015*
	2	14	27	17	

(b)	Soil texture			P value
	Clayey	Loamy	Sandy	
pH	6.48[a]	6.43[a]	6.03[b]	< 0.05
TOC $g\,kg^{-1}$	1.21[a]	0.99[b]	0.97[b]	
AP $mg\,kg^{-1}$	76.0[a]	76.1[a]	64.20[a]	
K $cmol\,kg^{-1}$	1.23[a]	1.09[a]	1.03[a]	
EC ds/m	0.09[a]	0.08[a]	0.07[a]	
WHC gH_2O g dry $soil^{-1}$	50.6[a]	39.4[b]	35.0[c]	

* $P < 0.05$.
** $P < 0.01$.

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

		Colour of major local soil types			P value
		Blackish ($n = 36$)	Reddish ($n = 19$)	No colour ($n = 50$)	
(a)					
Soil fertility evaluation	Best	35	13	5	0.000***
	Worst	1	6	45	
Village	1	12	14	23	0.017*
	2	24	5	27	
(b)					
pH		6.57^{a}	6.62^{a}	6.10^{b}	< 0.05
TOC g kg^{-1}		1.05^{ab}	1.19^{a}	0.97^{b}	
AP mg kg^{-1}		101^{a}	71^{ab}	54^{b}	
K cmol kg^{-1}		1.24^{a}	1.09^{a}	1.07^{a}	
EC ds/m^{-1}		0.10^{a}	0.07^{ab}	0.07^{b}	
WHC % gH_2O g dry $soil^{-1}$		47.8^{a}	44.1^{a}	37.8^{b}	

* $P < 0.05$.
*** $P < 0.001$.

indicators in the study area.

This simple approach to soil classification and evaluation may reflect the relatively short history of agriculture in this area. According to farmers' narratives of agricultural development in the region, soil knowledge and management has been shaped by social change. Traditionally farmers have evaluated the soil humus and texture to decide on the best locations for shifting cultivation since the 17th Century. These two indicators were also reported as common in indigenous soil classification in other areas (Barrera-Bassols and Zinck, 2003). However, these evaluations may not have been relied upon as much in the past because there was plentiful fertile land before 19th century. Increased settlement and the implementation of a land ownership system in the 1970s (Ikeno, 1989) restricted local farmers' traditional systems, with losses in the humus rich surface soil and soil erosion of some sub-soils. It is this reworked soil that is captured in the current local soil classification, but which may have been used for less than half a century. While nearby Machakos, another Kamba settlement, suffered degradation of its agricultural land up to the 1930s, a landownership system and introduction of terraces led to conservation improvements (Karanja et al., 2017; Tiffen et al., 1994). The story of agricultural extension in Kitui is however later than Machakos and there have been no large-scale land conservation project as within Machakos (Karanja et al., 2017, Ikeno, 1989, *personal communication with Extension Officers in Kitui*). Investment in terracing of fields has been ad hoc in Kitui and many have been damaged by high intensity rain. The growing population has placed pressure on forest resources, reduced farm sizes through traditional subdivision of land holdings for each generation, increased local food demand and required a more intensive farming approach (Ikeno, 1989). The narratives and soil knowledge reported by farmers in the study primarily reflects their experience after this period of social change.

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

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

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

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

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

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

5. Conclusion

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

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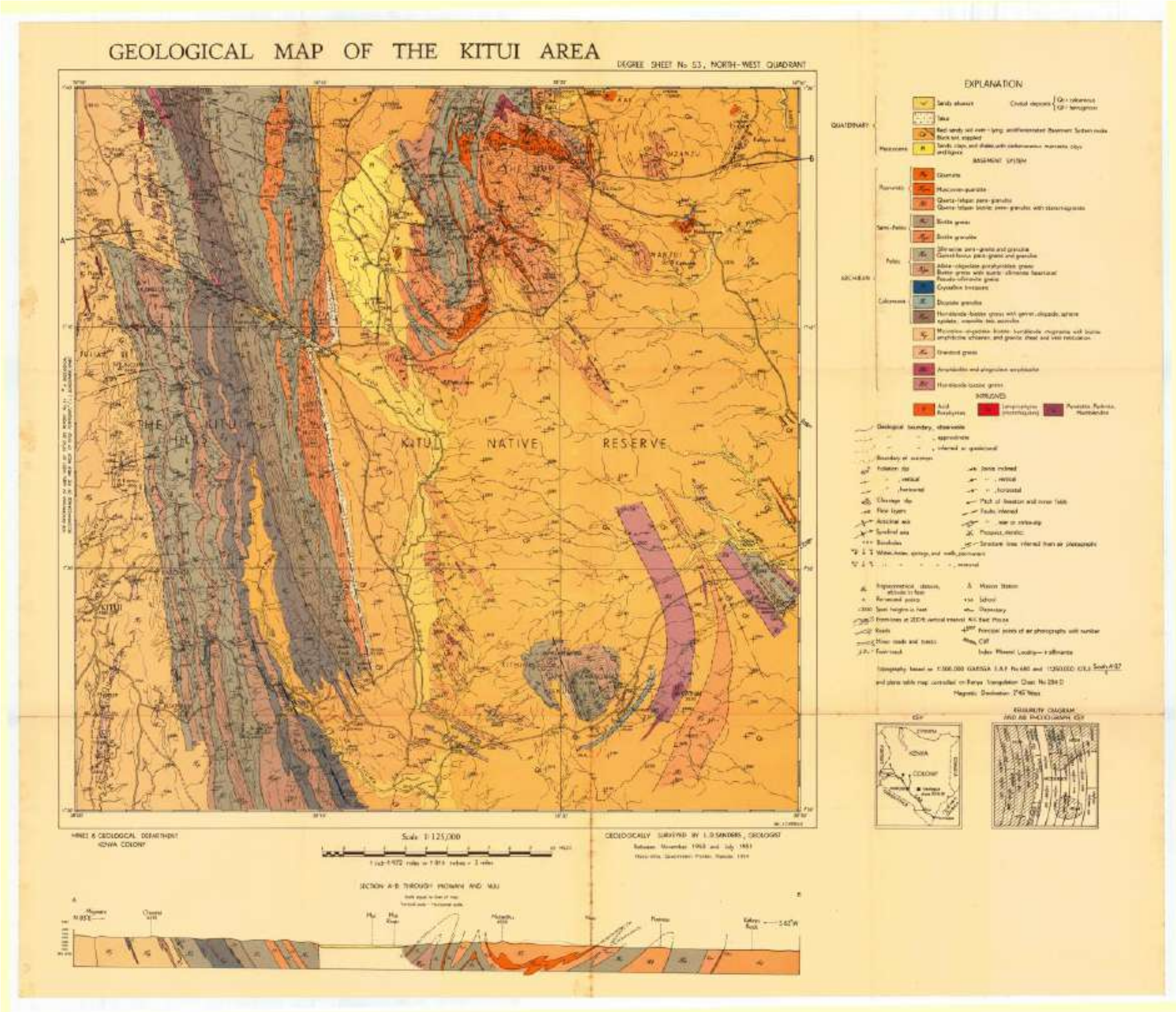
Appendix 2 Geological map of the study area



Appendix 3a: Information sheet for interview

Information Sheet for Interview

Reference Number

Soil scientists' thought about soil fertility

You are asked to answer an interview in a research study conducted by Ms. Yoshie YAGETA (Primary Investigator), a PhD student from the University of Reading, UK. The data from this study will contribute to my doctoral thesis, and will be used to write up papers for publication in peer reviewed journals.

The project is look at how soil scientists recognize soil fertility. The goal of this study is to understand the relationships between farmers' soil knowledge and soil scientific information, and then the findings are connected to the improvement of future extension actions and better communication.

Your identity will not be revealed to anyone other than the primary investigator because each participant has a unique reference number, and your name and contact detail are kept on a contact list separately. You are free to withdraw from the research activities at any time you feel uncomfortable or unwilling to participate, and you do not have to specify a reason. Any contribution can be withdrawn at any stage and removed from the research if desired. If you wish to withdraw, please contact Ms. Yoshie YAGETA (details below) by 21th September 2019, quoting the reference at the top of this page. The reference will only be used to identify your questionnaire and will not reveal any other information about you.

Written records, audio recordings and research notes will be secured by being kept strictly in my possession. All data stored in electronic form on a computer will be kept in a password-protected file, whose password is known only to the primary investigator and the supervisor, Dr. Henny Osbahr. At the end of the study (21th September 2019), the data will be destroyed.

If at any stage you wish to receive further information about the research activities or project please do not hesitate to contact Ms. Yoshie YAGETA and the supervisor, Dr. Henny Osbahr (contact details below).

By answering the questions, you are acknowledging that you understand the terms of participation and that you consent to these terms.

Ms. Yoshie YAGETA

PhD Researcher, University of Reading, y.yageta@pgr.reading.ac.uk, +447939153203 (UK)

Dr. Henny Osbahr
Associate professor, University of Reading, h.osbahr@reading.ac.uk, +4411833788314 (UK)

Appendix 3b: Information sheet for focus group

Information Sheet for Focus Group

ıce Number

Soil scientists' thought about soil fertility

You are asked to participate in a focus group in a research study conducted by Ms. Yoshie YAGETA (Primary Investigator), a PhD student from the University of Reading, UK. The data from this study will contribute to my doctoral thesis, and will be used to write up papers for publication in peer reviewed journals.

The project is look at how soil scientists recognize soil fertility. The goal of this study is to understand the relationships between farmers' soil knowledge and soil scientific information, and then the findings are connected to the improvement of future extension actions and better communication.

Your identity will not be revealed to anyone other than the primary investigator because each participant has a unique reference number, and your name and contact detail are kept on a contact list separately. You are free to withdraw from the research activities at any time you feel uncomfortable or unwilling to participate, and you do not have to specify a reason. Any contribution can be withdrawn at any stage and removed from the research if desired. If you wish to withdraw, please contact Ms. Yoshie YAGETA (details below) by 21th September 2019, quoting the reference at the top of this page. The reference will only be used to identify your questionnaire and will not reveal any other information about you.

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If at any stage you wish to receive further information about the research activities or project please do not hesitate to contact Ms. Yoshie YAGETA and the supervisor, Dr. Henny Osbahr (contact details below).

By answering the questions, you are acknowledging that you understand the terms of participation and that you consent to these terms.

This application has been reviewed according to the procedures specified by the University Research Ethics Committee and has been given a favourable ethical opinion for conduct.

Ms. Yoshie YAGETA

PhD Researcher, University of Reading, y.yageta@pgr.reading.ac.uk [redacted] (UK)

Dr. Henny Osbahr
Associate professor, University of Reading, h.osbahr@reading.ac.uk [redacted](UK)

Appendix 4: Questionnaire for structured interview
Questionnaire for Farmers **Interview date: . .2016**

[Part1: IDENTIFICATION DATA]
Interviewee basic information:

Reference code	Gender	Age
	(1) Male, (2) Female:	

Household type	Position of the interviewee in the household
1=Male headed; 2= Female headed; 3= Male headed but husband away	*1=head; 2=spouse; 3=parent; 4= son/daughter; 5=son/ daughter-in-law; 6=brother/sister; 7=Other (specify)*

GPS Coordinates:

Latitude	Longitude	Elevation (m)	Way point NO.

(a) 1=Upstream; 2=middle; 3= downstream

Education:

Last education				
language	Kamba	Swahili	English	Other ( )
Speaking				
Listening				
Reading				
Writing				

1=not 2=little 3=well understand

[Part 2: Household livelihoods structure]

Production systems

1. How long have you lived here? since________ year
2. How long have you owned this land? since________ year
3. How long have your family cultivate the home field? since ________ year

Income on farm:

crops ……………………%
Vegetables …………….%
Fruits……………………%
Animal………………… %
Off-farm…………………………%

Livestock production

1. Now we would like to learn what livestock you own presently (*number*):

Cattle	Bull	Goats	Donkey	Rabbit	Poultry	**TOTAL**

[Part3: Farm data]

Land

Land type	Family owned (Acre)	Rent (Acre)	Total
Home field			
Away field 1			
Away field 2			
Land for livestock			
Land not in use			
Total			

Part 2: Soil use and management by farmers under different weather conditions

	Crop type					
	Home field (best place)	Home field (worst place)	Away field 1(best place)	Away field 1(worst place	Away field2 (best place)	Away field 2(worst place
main						
2						
3						
4						
5						
6						
7						
8						
9						
10						
Soil type						
Reason						

[Part4: Detail of each field data and its change based on rain amount]

In a normal year, can you tell me which crops you would plant where. Please describe the soils in those fields and any information you use to help you make this decision. Please also explain how you would manage these soils for that crop during a 'normal' year. Would you get advice from people, if so who and what kind?

Soil type	Soil character (information for management decision)	Ranking of soil (production)	Crop (variety, purpose, performance)	Management (fertilizer, pesticide, tillage, terrace)	Advice?
1 Best soil in home field					
2. Worst soil in home field					
3. Best soil in away field					
4 Worst soil in away field					

Reason of ranking……………………………………………………………………………………………………

In a ‘less rain’ year, can you tell me which crops you would plant where. Please describe the soils in those fields and any information you use to help you make this decision. Please also explain how you would manage these soils for that crop during a ‘dry’ year

Soil type	Soil character (information for management decision)	Ranking of soil (production)	Crop (variety, purpose, performance)	Management (fertilizer, pesticide, tillage)	Advice?
1 Best soil in home field					
2. Worst soil in home field					
3. Best soil in away field					
4 Worst soil in away field					

Reason of ranking……………………………………………………………………………………………………

In a ‘Excessive rain’ year, can you tell me which crops you would plant where. Please describe the soils in those fields and any information you use to help you make this decision. Please also explain how you would manage these soils for that crop during in plenty rain year.

Soil type	Soil character (information for management decision)	Ranking of soil	Crop (variety, purpose, performance)	Management (fertilizer, pesticide, tillage)	Advice?
1 Best soil in home field					
2. Worst soil in home field					
3. Best soil in away field					
4 Worst soil in away field					

Reason of ranking………

[Part5: Source of information]

1. Have you and your family member participated in any agricultural group activity or project by organizations (NGOs/MoA)? Yes/ No

2. What organizations carry out the agricultural projects which you participate at present and past, and what are these projects?

Name	**Activity type**	**Project**	**Year**	**Who**

3. Which communication device do you have and do you use it for receiving agricultural information?

Device	|Hold	Use for agricultural information
Cell Phone		
TV		
Radio		
Smart phone/ PC		

[Part 6: Important thing for Agriculture]

1. How much are these items below important for your agricultural practices?

	Items	Not important 1 2 3 4 5 very important
1	soils	
2	water	
4	Seeds	
5	Fertilizer	
6	pest and disease management	
7	market access	
8	Agricultural loan	
9	agricultural knowledge	
10	Farmers group activity	
11	Other (specify here)	

2. Reason……………………………………………..

[Part7: Combination of Knowledge]

1. How much you trust local traditional practices and agricultural officer? Time

local: low trust 1-2-3-4-5 high trust
Extension: low trust 1-2-3-4-5 high trust

2. Which is higher trust? Indigenous/ External

3. Why?……………………………………………………………………………………………… ……………………………………………………………………………………………… ……………………………………………………………………………………………… ……

4. For what purpose you use indigenous and external knowledge?

Indigenous:……………………………………………………………………….
External:………………………………………………………………………..

5. Please tell one story when you change traditional practice to new methods

………………………………………………………………………………………………… ……………….
………………………………………………………………………………………………… ……………

[Part8: Demand of soil knowledge]

1. Do you want to know more about soil? Yes/ No

2. Why?……………………………………………………………………………..

3. When do you think so?...

4. If yes, what kind of information do you want?

………………………………………………………………………………………………… …………………………………………….

This is the end of the questionnaire. Thank you very much for your participation.

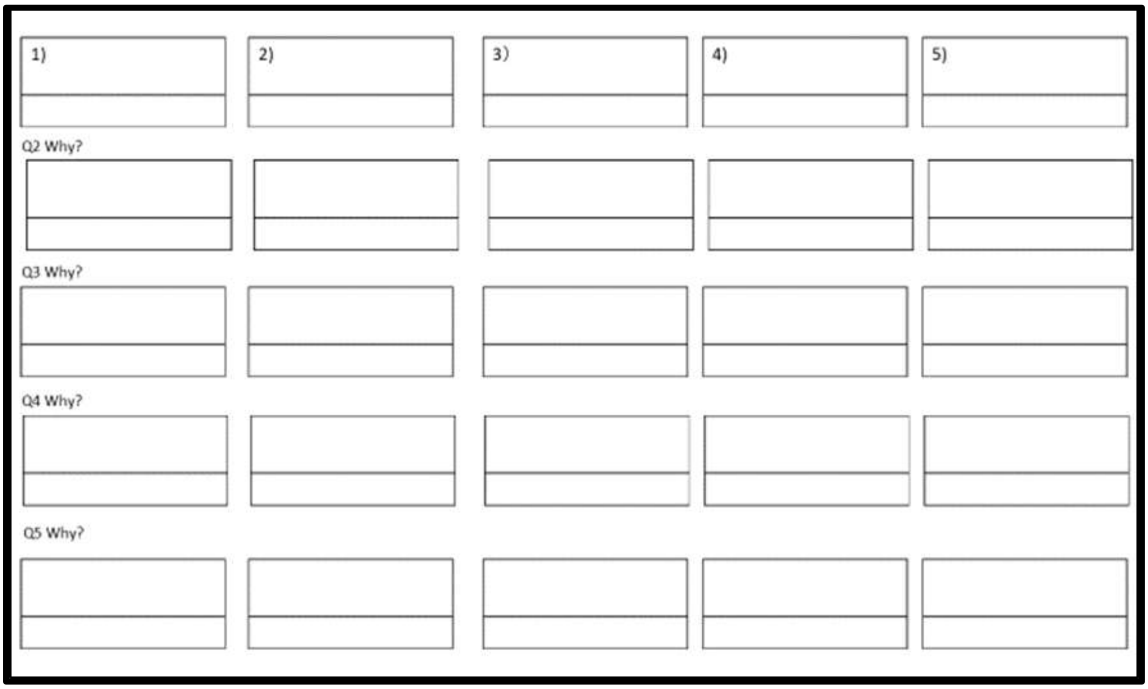
Appendix 5: Participatory methods

a) Casual diagram

[Process]

1. White the maize variety, vegetable type, and another one specific plant in the field of fertile/ low fertility soils
2. Ask "Why do you plant the plants in the place?
3. Ask why "the answer of the 1st question" (e.g. why water penetrate so fast?)
4. Ask why "the answer of the 2nd question" (e.g. why the pores in soil are smaller?
5. Ask why "the answer of the 3rd question" (e.g. why the particles in the soil are smaller?)

Until they said they don't know. Connected each column by red allow.



b) Seasonal calendar

Month rain	8	9	10	11	12	1	2	3	4	5	6	7	8
Crop and location List key													
INPUTS Labour (No. people, No. days, gender, activity) Cash Fertiliser Manure Other													
OUTPUTs Harvest (yield) Income													

c) Alternative structured interview sheet with the reasons for the decisions made for the management of each field

Question		Answer	Reason
What is your main information source about agriculture ingeneral?			
Manure	What type?		
	How to apply		
	Where is priority?		
Fertilizer	For which crop?		
	What type?		
	How to apply		
	Where is priority?		
Pesticide	For which crop?		
	Where is priority?		
Terrace	When constructed?		
	When renewed?		
	Who dug it?		
Time of plant	When plant?		
	How to plough		
	Which maize variety is chosen for short rain season?		
	Do you plant cawpea, green gram and beans in short rain season?		
Labour	Where do you use labour?		
	For what purpose?		

Appendix 6: Contents of Focus group discussion

a) Historical narratives

1. When did the surveyors visit your village?
2. The environment and social condition before surveyor come
3. Characteristics of previous soil compared with current
4. Indigenous way of land management

4.1. How did your family decide lands to cultivate?

4.2. Were their special soil characters for specific crops (soil type, texture, vegetation)?

b) Time line of historical events and Livelihoods strategy in the village

<u>Timeline</u>

1. (Purpose: to know the change of lifestyle especially farming style in this village)
2. Including contents
3. Extension of external knowledge (when and from who, hybrid seeds, chemical fertilizer, manure, decomposed manure, plough, jembe, muthya, terrace, mitunda)
4. Change of plant type, fruit, vegetable (what is dominant until/from when)
5. Change of transportation (matatu, boarder-border)
6. Change of information device (mobile, radio, TV)
7. Main historical events (road construction, government/ policy change, famine, elninyo) what happen and what they are affected?
8. Change of soil (by certain events or gradually? better or worse?)
9. Disappear/existence of indigenous knowledge (zigzag planting, dig by stick, plant various seeds in one hole, distributing seeds, misonzo, utaa etc.)

<u>Livelihood strategy</u>

1. (purpose: to know the characteristics of input and output in this village)
2. What are major income sources (listing), What made more income (ranking)

What are major expenditures for agriculture, animal, and other livelihoods (listing), What are more expensive (ranking)

Appendix 7: Questionnaire sheet of interview for agricultural extension officers

Question for Extension officer Office: Reference No Date:

1. About Work	Answers
General	
1week time table	Mon
	Tue
	Wed
	Thr
	Fri
History of Extension (TandV)	
2. History of introduction (ask year)	
Hoe	
Plough	
Manure	
Fertilizer	
Compost	
Terrace	
Nepia Grass	
Mitunda	
Pesticide	
Postharvest chemical	
PH plastic bag	
3. Failure of Extension	
Item, project	
Reason	
4. Problem from Farmers	
Main	
Solution	
Stagnate maize in Nthangathi	
5. Problem on extension	
Main	
Reason	
6. Communication with farmers	
Frequency	
Type of farmers	
Area	
Reason	
Difficulty	
7. Soil	
What is character of good soil?	
How do you know good soil?	
How to learn about soil?	
How much is soil important for your work?	
What kind of information do you share with farmers related to soil?	
Do you know local soil classification?	
8. Q for Nthangathi	
How to make stronger terrace on Nthangathi	
Suitable plant (variety)	
Suitable fertility management	
9. Q for Kitambasyee	
Why beans not grow well?	
Why seed rotten if plant before rain?	

Appendix 8: Soil analysis methods

Soil water holding capacity Apparatus:

Small plastic containers with mesh on the bottom (or plastic drinks cups with holes)
Retort stands and clamps
Bucket
Beakers (or something to put under containers during the draining phase)
Small tins for oven drying soil at 105 °C
Cling film

Method:

Place approximately 50 g of air-dry soil in an appropriate plastic container (you can use less soil if you have a limited quantity). There is no need to weigh the container first and no need to record the exact amount of soil added.

Place the containers in a dish of water, and allow the soil to become saturated. You may choose the period of soaking to suit your own lab program as long as you treat all replicates and samples the same - approximately 6-12 hours soaking time is suggested.

Remove the containers from the water and cover them with cling-film to prevent loss of water by evaporation from the soil surface.

Suspend the containers on a retort stand to allow drainage. This is probably best done overnight, therefore 12 - 16 hours drainage time is recommended. Again, ensure that all samples are allowed to drain for the same amount of tune.

Remove approximately half of the wet soil from each container and place in a ***preweighed*** aluminium dish. You will need to record a) the mass of the dish, and b) the mass of the wet soil + dish.

Place in oven at 105 °C for at least 24 hours or until no further water loss occurs (i.e. no further decrease in mass is recorded).

Remove the dishes from the oven and place in a desiccator to cool. Weigh the dish

with the oven dry soil and record the mass. Calculate the water holding capacity as

follows:

WHC (%) = mass of drained soil - mass of oven dried soil x 100 mass of oven dried soil

* It should be noted that it is likely that this method overestimates the WHC for sandy soils.

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DEPARTMENT OF LAND RESOURCE MANAGEMENT AND AGRICULTURAL TECHNOLOGY

pH Determination

Determination of Soil pH

The pH (reaction) of the soil is determined, using a pH meter and glass electrodes. The pH as measured in the laboratory is affected to a slight extent by the ratio of soil to water or solution used. In some laboratories one part of water is mixed with one part of soil to give a paste into which the electrode or electrodes are inserted. Most soil laboratories, however, now use more water than this: one part of soil to two parts of water is a common ratio. This allows better contact between electrodes and the soil/water suspension.

The pH of the soil will be determined using one part of soil to 2.5 parts of water or solution, e.g. 10.0g soil to 25ml water. The pH is normally determined using distilled or deionised water. The soil/water mixture is allowed to come into equilibrum:20 to 30minutes should preferably be allowed for this, with stirring or shaking at intervals, and then the suspension should be allowed to settle so as to give a layer of fairly clear supernatant water above a lower layer containing soil in suspension. If there are two separate electrodes adjust them so that the glass electrode is a little lower than the calomel reference electrode so that, on lowering into the suspension, the glass electrode is in the lower layer containing suspended soil but the reference electrode is in the clear supernatant liquid. Then both electrodes are lowered into the partly settled suspension, and the pH read on the meter.

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Department of Land Resource Management and Agricultural Technology

Telephone: [redacted] (DL) [redacted]-9 Ext. [redacted] P.O. BOX 29053-00625
Fax: [redacted] Email: larmat@uonbi.ac.ke Nairobi, Kenya

Electrical Conductivity

Soil salinity refers to the concentration of soluble inorganic salts in the soil*. It is normally measured by extracting the soil sample with water (1:1 or 1:5 soil: water ratio, w/v) or in an extract saturated paste. However, soil: solution ratios of a 1:1 or wider are more convenient where the quantity of soil is limited. Such extracts are rapid, and salinity is measured by* ***electrical conductivity*** *(EC) using a conductivity bridge. The total salt content of a soil can be estimated from this measurement.* ***Salinity*** *is an important laboratory measurement since it reflects the extent to which the soil is suitable for growing crops. However, salinity affects plants at all stages of development and for some crop's sensitivity varies from one growth stage to another. While salinity is largely a concern in irrigated areas and in areas with saline soils, it is often less important in rainfed agriculture. However, with increasing use of irrigation, there will be greater emphasis on EC measurement in the future. The basic methodology and principles of EC measurement is given in USDA Handbook 60 (Richards, 1954).*

On the basis of a saturation extract, values of 0 to 2 dS/m are safe for all crops; yields of very sensitive crops are affected between 2 to 4 dS/m; many crops are affected between 4 and 8 dS/m; while only tolerant crops grow reasonably well above that level

Apparatus: Conductivity bridge/EC Meter
Reagent

Potassium Chloride Solution (KCl), 0.01 *N*

Dry a small quantity of reagent-grade *KCl* in an oven at 60 °C for 2 hours, cool in a desiccator, and store in a tightly stoppered bottle.

Dissolve 0.7456 g *KCl* in DI water and transfer to 1-L flask, mix well, and bring to volume. This solution gives an electrical conductivity of 1.413 dS/m at 25 °C.

Procedure

1. Weigh 50 g air-dry soil (< 2-mm) into a 100-mL glass beaker, as for pH determination.
2. Add 50 mL DI water using a graduated cylinder or 50-mL volumetric flask.
3. Mix well with a glass rod, and allow to stand for 30 minutes.
4. Stir suspension every 10 minutes during this period.
5. After 1 hour, stir the suspension.
6. Calibrate the conductivity meter according to maker's instructions
7. Transfer the clear filtrate into a 50-mL bottle, immerse the conductivity cell in the solution, and take the reading.
8. Remove the conductivity cell from the solution, rinse thoroughly with DI water, and dry excess water with a tissue.

Technical Remarks

1. Readings are recorded in deci-Siemens per meter (dS/m).

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The determination of organic carbon in the soil by the Walkley-Black method.

In order to determine the organic matter (i.e. humus) content of the soil a number of possible methods can be used. However, the most common method is to measure the carbon in the organic matter by oxidizing it, and then to multiply the carbon content by a factor which reflects the average carbon content of the soil organic fraction. It is usually assumed that carbon forms an average of 58% of soil organic matter, so that the percentage carbon found is multiplied by 1.724 to give the percentage organic matter

A number of methods are available to measure the organic carbon. Some of them oxidize all the carbon present in the soil sample (as when a soil sample is ignited in a stream of oxygen and the $C0_2$ evolved is measured) but in others only part of the organic carbon is oxidized. It is quite satisfactory to oxidize only a fraction of the carbon present, provided that the percentage of the total carbon that is oxidized by the method (the percentage recovery) is also known. Moreover, what is needed is a method which attacks only the easily oxidizable carbon of the organic matter, and which leaves intact other possible forms of carbon which are not part of the humus fraction, such as, for example, raw organic matter or charcoal fragments which may be present in the sample.

The walkley-Black method of oxidizing the organic carbon in the soil, described here, has become the most widely used routine method of determining organic carbon in soil laboratories because it is relatively simple, because it gives reproductive results, and because it attacks the more easily oxidizable carbon in the soil organic fraction, and does not attack 90-95% of any elementary carbon (such as charcoal or graphite) which may be present. On most soils the method has a recovery of about 77% i.e. it oxidizes about 77% of the carbon of the soil organic fraction, and this factor is taken into account in the formula given below for calculating the results.

In the Walkley-Black method, the carbon is oxidized with potassium dichromate ($K_2Cr_20_7$) in the presence of concentrated (36N) sulphuric acid. Potassium dichromate is added to a carefully weighed sample of soil ground to pass a 0.5mm sieve and then the concentrated sulphuric acid is rapidly added: the heat of dilution obtains by diluting 20ml of acid with 10ml of dichromate is a convenient way of supplying a standard amount of heat to assist the oxidation. (In an alternative method, heat is applied from an outside source: depending on the amount of heat supplied, greater
Percentages of the organic carbon are oxidized by the Walkley-Black method). After the mixture is allowed to cool, the amount of dichromate used up in the reaction is determined by reducing the remaining dichromate with ferrous sulphate (or ferrous ammonium sulphate) of known normality (usually 0.5 or 0.2N) in a simple titration using diphenylamine or barium diphenylamine sulphonate as an indicator. The potassium dichromate in the presence of the sulphuric acid becomes chromic acid. The formula for the oxidation of the carbon is as follows:

$$2\ K_2Cr_207 + 8H_2S04 + 3C = 2K_2S04 + 2Cr_2(S04)_3 + 8H_20 + 3C0_2.$$

a) Preparation of the soil sample

A soil sample which has previously been passed through a 2mm sieve to remove the coarse fraction is ground to pass a 0.5mm sieve. This is to increase the homogenization of the sample and to facilitate the oxidation.

b) Oxidation with potassium dichromate

1. A sample of soil is carefully weighed and put into an Erlenmeyer (conical) flask. The amount of soil used depends on its organic carbon content. A 1.0g sample is suitable for soils having about 1-2%C; with more carbon than this (about 3-5%) a sample of 0.5g is taken but when the soil contains less than 1% carbon then a more accurate result is obtained when 2.0g of soil is taken. (The carbon content of the sample should be sufficient to use up between about 20-80% of the 10ml of dichromate added: with a 1.0g sample this means that there should be between 0.6% and 2.4% carbon in the sample: if there is more than 3% carbon, the dichromate will be insufficient to oxidise it all).

2. Add 10.0ml of 1N potassium dichromate with a pipette, and allow to come into contact with the whole sample by swirling gently (NB do not swirl in such a way that some of the soil sticks to the side of the flask where it is then out of contact with the reagents added).

3. Measure out 20ml of concentrated (36N) sulphuric acid in a measuring cylinder. Pour this in a steady stream into the center of the soil-dichromate mixture. There will be an immediate reaction, including some bubbling, and considerable heat will be produced: place on a sheet of asbestos and allow cooling for about 20 minutes.

c) Titration of unused potassium dichromate

4. Add distilled water to bring the volume to about 200ml. Add 5.0ml 85% orthophosphoric acid (H_3P0_4) and about 5.0ml of diphenylamine sulphonate indicator. The phosphoric acid gives the environment necessary to obtain a good end point when titrating with ferrous sulphate.

   or use 1-10 phenanthroline the colour will change to bright red

5. Titrate with 0.5N ferrous sulphate (or ferrous ammonium sulphate), the exact normality of which should have been obtained by titrating 10.0ml of dichromate in a blank (i.e. processing as above, except that there is no soil in the blank). As the end point is approached the turbid dark blue colour becomes greenish, changing to a clear pale green quite sharply at the end point itself. With practice, a one drop end point can be obtained. If the end point is over-stepped, or in order to check the result a second time, add a known amount of dichromate (e.g. 0.5ml) sufficiency to change the contents of the flask back to blue, then add ferrous sulphate very carefully to obtain a second and point. If this procedure is used, the extra dichromate added must be included in the calculation (e.g. 10.5ml instead of 10.0ml).

c) Calculation of percentage carbon in the sample

The percentage of carbon in the soil is calculated according to the following formula, which takes into account the fact that 1ml of N dichromate oxidizes 3mg of carbon

N=10/Vblank…………………………………………………………………1

%Oxidizable organic carbon= $\frac{(VBlank-VSample)\ x0.3xN}{Wt}$………………………2

%Total organic carbon=100/77 x oxidizable organic carbon………………3

Where

N=Normality of Ferrous sulphate

Vblank=volume of Ferrous sulphate solution required to titrate the blank

Vsample = volume of Ferrous sulphate solution required to titrate the sample

Wt = weight of air-dry soil

$0.3=3*10^3$ where 3is equivalent weight of carbon

If normal dichromate is used, the m.e. of dichromate are the same as the ml of dichromate used (10.0, or a little more if the back-titration techniques is employed), while the m.e. of ferrous sulphate used is obtained by multiplying the ml used in the titration by the normality of the $FeS0_4$ as obtained in the blank titration.

The figure obtained in this way gives the actual amount of carbon oxidized by the dichromate. This is sometimes referred to as the uncorrected Walkley-black value, since it does not take into account the fact that the average recovery is about 77%. If we assume that the 77% figure applies to the particular soils analysed, and wish to correct for this, then the result obtained with the above formula must be multiplied by 100, or alternatively the 0.3 in the formula is changed 77 to 0.39, since with a 77% recovery each m.e. of dichromate is equivalent to 3.9mg carbon, and not 3.0mg

REAGENTS

1. IN potassium Dichromate ($K_2C_{r2}0_7$): dissolve 49.04g of

Analytical grade dichromate (dried at 105°C) in distilled water and make up to 1,000ml.

2. Conc. (36N) H_2S0_4.

3. Conc. Orth phosphoric acid H_3P0_4.

4. Barium diphenylamine sulphonate: 0.1% solution in 5% barium chloride.

5.0.5N ferrous sulphate: dissolve 140g of reagent grade FeS04. 7H20 (or 196g ferrous ammonium sulphate) in water, add 5ml conc. Sulphuric acid, cool and make up to 1,00ml.

Chairman,
Dept., of LARMAT---Date-------------------------------

UNIVERSITY OF NAIROBI
COLLEGE OF AGRICULTURE & VETERINARY SCIENCES
Department of Land Resource Management & Agricultural Technology
Telephone: [redacted] (DL) 3[redacted]Ext.2[redacted] P.O. BOX 29053-00625
Fax: [redacted] Email: larmat@uonbi.ac.ke Nairobi, Kenya

TOTAL NITROGEN PRACTICALS.

Objectives

To show students the methods used in the analysis of total nitrogen

To familiarize the students with the equipment and chemicals used in nitrogen analysis.

Kjedhal apparatus

Steam distillation

Titration

Total Nitrogen Analysis

Reagents

Conc sulphuric acid

Potassium sulphate 160.0g, Copper Sulphate l0g, Selenium powder 3g. (Mixed catalyst)

Saturated sodium hydroxide (40%)

Boric acid 2%

Dilute sulphuric acid (0.0IN).

Methyl red 0.12 in 100ml of 95% ethanol (mixed indicator).

Procedure

I. Weigh 1gm of air-dried soil sample into 250ml digestion flask.
II. Add a scoop of mixed catalyst (lg) and 8ml of concentrated sulphuric acid.
III. Shake gently for the acid and the contents to mix properly place in a Khejdahl digestion block and commence digestion low temperatures 120oC for one hour.
IV. Raise the temperature to 330C and continue heating. The solution should now be colourless and any remaining sand white. If solution is still coloured, continue heating until this is achieved.

V. Allow contents to cool.

VI. Add about 25-ml distilled water and mix well until no more sediment dissolves. Allow to cool and make up to 50 ml with water.

VII. Allow to settle so that a clear solution can be taken from the top of the tube for analysis.

VIII. Take an aliquot of 10mIs into a khejdahl distillation flask and fix it into the distillation system. Add quickly 10 mls of 40% sodium hydroxide through the ancillary mouth of the flask, and start distillation into the 2% boric acid containing 4 drops of the mixed indicator in the 250ml conical flask.

IX. Titrate contents with sulphuric acid 0.01N back to pink colour from green colour.

Equation

$NH_3 + H_3BO_3$ __________ $NH_4 + H_2\ BO_3$

$NH4^+ + H_2BO_3 - + H_2SO_4$ ________________ $NH_4HSO_4 + H_3BO_3$

i.e.

% Total N=

$$\frac{\text{(Titre x 14 x Normality of Acid used x Vol Extracted x100\%}}{\text{Wt. of sample x 1000xAliquot taken in ml}}$$

(Van Schouwenberg and Walinge, 1973).

Ammonium Nitrogen and Nitrate Nitrogen

Principle

Nitrogen is a major element essential for plant growth because it is a constituent of all proteins and nucleic acids. The majority of soil nitrogen resides in organic matter, but this N is continuously being mineralized into NH4+ and NO3- ions, the forms assimilated by plants. This reflects the need to measure the forms and subsequent movement patterns of these ions in soils during cropping in order to make informed recommendations on the need and rates of N-bearing fertilizers and organic inputs. The method provided below provides measurements of NH4-N and NO3-N from a single soil extract. Use of MgO makes the extracts alkaline to enhance NH4-N determination, while Devarda's alloy reduces NO3-N to NH4 that is then readily measured through steam distillation.

NH4-H and NO3-N estimates in soil are simultaneously extracted in fresh soils using 0.5 M K2SO4 followed by faster accurate colourimetric estimates. The colourimetric method described below provides measurements of NH4-N and NO3-N from a single soil extract. Manual procedures are fully described in this chapter. In the colourimetric procedure the nitrites are reduced to nitrates which react with sulphanilamide and -naphthyl-ethylenediamine dihydrochloride to form a highly coloured diazo dye which forms the bases for this analysis.

Ammonium nitrogen and NO3-N plus NO2-N are determined by steam distillation, using ***heavy MgO*** *for NH4 and* ***Devarda's Alloy*** *for NO3. The distillate is collected in saturated H3BO3 and titrated to pH 5.0 with dilute H2SO4.*

Apparatus

Distillation unit

Automatic titrator

Stirrer

Reagents

A. Magnesium Oxide (MgO), powder

Heat heavy *magnesium oxide* in a muffle furnace at 600-700 °C for 2 hours, and cool in a desiccator containing KOH pellets, and store in a tightly stoppered bottle.

B. Devarda's Alloy (50 Cu: 45 Al: 5 Zn)

Ball-mill reagent-grade *Devarda's Alloy* until the product will pass a 100-mesh sieve (0.150 mm) and at least 75% will pass a 300-mesh sieve (0.05 mm).

D. Boric Acid Solution (H3BO3), saturated

Add 500 g *H3BO3* into a 5-L volume.

Add 3-L DI water, and swirl vigorously.

Leave overnight.

G. Sulfuric Acid Solution (H_2SO_4), 0.01 *N*

Add 28 mL concentrated *H_2SO_4*, to about 600 – 800 mL DI water in a 1-L flask, mix well, let it cool, and bring to 1-L volume. This solution contains 1 *N* H_2SO_4 solution (*Stock Solution)*.

Pipette 10 mL *Stock Solution* to 1-L flask, and bring to volume with DI water. This solution contains 0.01 *N* H_2SO_4.

H. Standard Stock Solution

Dry reagent-grade *ammonium sulphate $(NH_4)_2SO_4$*, and *potassium nitrate* (*KNO_3*) in an oven at 100 °C for 2 h, cool in a desiccator, and store in a tightly stoppered bottle.

Dissolve 5.6605 g *$(NH_4)_2SO_4$* and 8.6624 g *KNO_3* in DI water, and bring to 1-L volume. This solution contains (1.2 g NH_4-N, and 1.2 g NO_3-N)/L (*Stock Solution)*.

Prepare a *Standard Solution* from the *Stock Solution* as follows:

Dilute 50 mL *Stock Solution* to 1-L volume by adding 2 *M KCl* solution (*Diluted Stock Solution*).
A 20-mL aliquot of *Diluted Stock Solution contains* 1.2 mg NH_4-N and 1.2 mg NO_3-N.

Soil Extraction.

Weigh 10.0 g of freshly sampled soil sample (or sample kept in a refrigerator) into a plastic shaking bottle. Add 100 ml of 2 M KCl extracting solution. Stopper and shake contents for 1 hour. Filter through No. 5 or No. 42 Whatman filter paper. If analysis will not be complete in one day, store the filtrate in a refrigerator. Microbial activity, associated with N-mineralization may also be suppressed by storing the extract under refrigerator when the distillation cannot be conducted immediately
Procedure

A. Pre-treatment of the distillation unit

1. The distillation unit should be steamed out for at least 10 minutes. Adjust steam rate to 7-8 mL distillate/minute.

2. Water should flow through the condenser jacket at a rate sufficient to keep distillate temperature below 22 °C.

B. Distillation

1. Before starting a batch for distillation, the distillation unit should be steamed out for at least 10 minutes. Adjust steam rate to 7 – 8 mL distillate per minute. Water should flow through the condenser jacket at a rate sufficient to keep distillate temperature below 22 °C.

2. Carry out distillations as follows:

To determine NH_4-N

Pipette 20 mL soil sample into a 100-mL distillation flask.

Pipette 5 mL **saturated H_3BO_3** solution and 1 mL DI water into a 50-mL beaker (duplicate beakers).

Place the first beaker underneath the condenser tip, with the tip touching the solution surface.

Add about 0.2 g **heavy MgO**, with a calibrated spoon, to the distillation flask.

Immediately, attach the distillation flask to the distillation unit with a clamp.

Start distillation, and continue for 3 minutes, then lower the dish to allow distillate to drain freely into the Pyrex evaporating dish or beaker.

After 4 minutes, when 35-mL distillate or more is collected, turn off the steam supply and remove the distillation flask (***first distillate***).

 Each distillation should contain at least two standards (pipette 20 mL 1.2 mg NH_4-N from *Diluted Stock Solution*) and two blanks (pipette 20 mL 2 KCl solution). Recovery of NH_4-N should be at least 96 %.

To determine NO_3-N

Place the second beaker underneath the condenser tip, with the tip touching the solution surface.

Immediately, add 0.2 g **Devarda's alloy**, with a calibrated spoon, **to the same distillation flask**, then attach back to distillation unit with a clamp, and start distilling.

After 4 minutes, when 35-mL distillate or more is collected, turn off the steam supply and remove the distillation flask (***second distillate***).

Wash tip of the condenser into Pyrex evaporating dish or the beaker with a small amount of DI water.

Each distillation should contain at least two standards (pipette 20 mL 1.2 mg NO3-N from *Diluted Stock Solution*) and two blanks (pipette 20 mL DI water). Recovery of NO3-N should be at least 96 %.

C. Titration

Titrate the first distillate (for ammonia) and the second distillate (for nitrate), separately, to **pink colour** with standardized **0.01 *N* H2SO4** using an **Auto-Titrator**.

Notes

 After finishing titration, wash the Teflon-coated magnetic stirring bar, the burette tip, and the combined electrode into the dish.

 Between different samples, steam out the distillations. Disconnect distillation flasks containing the water sample, and attach a 100-mL empty distillation flask to distillation unit, and place a 100-mL empty beaker underneath the condenser tip, turn off cooling water supply (drain the water from the condenser jacket), and steam out for 90 seconds. Steaming-out is done only between distillation for different samples, not between ammonium (MgO) and nitrate (Devarda's alloy) in the same sample.

Calculation

$$NH_4 - N \text{ or } NO_3 - \text{N} \ (ppm) = \frac{(V - B) \times N \times 14.01 \times 1000}{V_1}$$

Where:

V = Volume of 0.01 N H_2SO_4 titrated for the water sample (mL)

B = Distillate blank titration volume (mL)

N = Normality of H_2SO_4 solution

V_1 = Volume of water sample used for distillation (mL)

14.01 = Atomic weight of N

UNIVERSITY OF NAIROBI
COLLEGE OF AGRICULTURE & VETERINARY SCIENCES
Department of Land Resource Management & Agricultural Technology
Telephone: [redacted] (DL) [redacted] Ext.[redacted] P.O. BOX [redacted] Fax: [redacted] Email: larmat@uonbi.ac.ke
Nairobi, Kenya

SOIL SCIENCE SECTION

Calorimetric Determination of soil Phosphorus (MEHLICH 1)

Extractant: Double acid (DA) which is 0.05 N HCI in 0.025 N H_2S0_4

(Involving Ascorbic acid).

Apparatus: SP500 Spectrophotometer.

Reagents:

Double acid: 0.05 N.HCI in 0.025 N. H_2 $S0_4$. This is prepared by pouring about 151itres of distilled water into 20 - litter bottle and adding 14 ml of a concentrated H_2S0_4 and 83ml of concentrated HCI. The volume made to 201itres and thoroughly mixed (proportional but less amounts of acids are used if the *total* volume of DA required is less than 20 litters).

Reagent A

1. Dissolve12g of Ammonium molybdate in *250ml distilled water*.
2. Dissolve 0.2908g of potassium antimony tartrate ($KSb0C_4H0_4$ *in100ml* of distilled water.
3. Prepare 5 N H_2S0_4 by diluting approx. 148 ml of cone. H_2S0_4 in about 1000ml of distilled water.
4. Mix solution 1,2 and 3 together in a 2-litre volumetric flask and make up to volume with distilled water.

Reagent B

Dissolve *1.056 g* of ascorbic acid to every 200ml of reagent A.

Note: Reagent B must be freshly prepared from reagent A each time before use;

Standard P Stock solution

Weigh *0.4393* of monobasic potassium phosphate (KH_2P0_4) into a 1-litre volumetric flask. Add *500ml* of distilled water and shake the contents *until* the salt dissolves. Make to volume with distilled water. Add 5 drops of toluene to diminish microbial activity. This solution contains 0.1 mg P/ml

(l00ppm or *l00 ugP/ml.)*

<u>Secondary P Standard solution</u>

Pipette 5 ml of the 100 ppm P stock solution into a 100-ml volumetric flask and make up to volume with distilled water. This solution contains 5 ppm P (or 5ug p/ml.

Soil Extraction

A 5.0 – 0.5mm g sample of each soil is weighed into a 100 -ml or 125 -ml extracting tube (or bottle) and 50ml of Double Acid reagent are added accurately with a pipette. The tubes are stoppered tightly (to prevent any leakage), placed horizontally in a rack on a mechanical, reciprocating shaker and shaken for 30 minutes.

With the assistance of technical staff, the soils are filtered through Whatman No. 2 filter paper (filter speed: medium) collecting the filtrate in specimen bottles. It is necessary to shake the extracts every time just before transferring them into the filter paper rather than simply decanting off the supernatants. Do not fill the filter paper to the brim and ensure that no soil goes behind the filter papers.

If the filtrates contain soil particles filter again into a clean specimen bottle using a clean filter paper preferably Whatman No. 42 (filter speed: slow). If soil particles are present in the filtrates they will interfere with the analysis.

N.B. Some colours are not due to the presence of soil particles but rather to organic matter. Nothing can be done to eliminate such colours since filter papers cannot retain them.

It is necessary to exercise care at every stage so that meaningful results can be obtained. If a mistake is made at any step it is necessary to repeat the procedure. It must be noted that the whole procedure from the beginning to die end is done in duplicate. It would even be better to do it in triplicate but shortage of apparatus and time do not allow.

The filtered extracted solutions are used for analysis.

<u>Analytical Procedure</u>

A. Prepare a set of standard P solutions by pipetting zero, 1,2,3,4 and 5ml of the 5ppm secondary standard into 50-ml volumetric flasks. To each of the flasks add 5 ml Double Acid followed by 20ml of distilled water. Add 8ml of reagent B to each flask and immediately make to volume with distilled water and mix thoroughly. Ensure thorough mixing immediately after distilled water is added to the mark.

Allow to stand for 15 minutes before taking the reading (absorbance) with the spectrophotometer. The data will be used to draw a calibration curve by plotting absorbance (V-axis) against P concentrations of the stds (H-axis). A suitably large graph (A4 size) should be drawn. The standard curve will be used to determine P concentrations in the soil extracts (filtrates) by converting absorbance to the corresponding P concentrations (a usual approach).

Pipette 1ml aliquot of the 0 to 15 cm depth soil extract into a 50-ml volumetric flask. Add approx. 25ml of distilled water followed by 8 ml of reagent B and immediately add distilled water to the mark and mix thoroughly.

Allow to stand for 15 minutes before taking the readings.

Pipette 10ml aliquot of the 15 to 30 cm depth soil extracts and does the above.

Calculations

The concentrations of P in the filtrates will be used to calculate the status of the original soils by taking into account the weight of soil used, the volume of the extractant (Double Acid), the final volume of the (coloured) solution, and the aliquot of the filtrate taken (i.e. pipetted for analysis).NB If the colour obtained with any extract is deeper than for the max. standard it is necessary to repeat the analysis by taking a smaller aliquot and proceeding as before. It is wrong to dilute the coloured solutions.

Note: Every student is required to pay full attention to all the procedures. Furthermore, everyone is required to record the data, draw a graph and determine the P content of the soil.

Make an effort to understand the calculations involved m the preparation of P standards.

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Department of Land Resource Management and Agricultural Technology

Determination of Cation exchange Capacity (CEC) and Exchangeable Bases

1.0 **Introduction**

Clay minerals hydrous oxides and humus possess negative charges which are neutralized by the adsorption of cations such as Al, H, Ca, Mg, N, Na and Mn. The total number of negative charges in a soil that are balanced by exchangeable cations is referred to as the soils cation exchange capacity (CEC). The units of CEC are usually given as me/100g soil or me/kg soil.

NOTE: 1 me = 1 milli equivalent, where 1 equivalent is the atomic weight of hydrogen or the amount of any other ion that will displace it, since 1 atom of a divalent cation e.g.
Ca^{2+} will displace 2 H atoms, the atomic weight of Ca=2 equivalents. Similarly, since 1 atom of a trivalent cation e.g. $A1^{3+}$ will displace 3 H atoms, the atomic weight of A l = 3 equivalents.

The exchangeable acidity in a soil is the exchangeable Al and H present which can be leached out with N. KCL. The exchangeable bases in a soil are Ca, Mg, K and Na. The bases are important since they are essential plant nutrients, unlike H and Al. The % base saturation of a soil is therefore an important index of a soils (Ca +Mg +K+ Na) 100%

CEC

2. Total Exchangeable Bases

Exchangeable Ca, Mg Na and K are extracted from the soil by leaching with IM ammonium acetate.

Procedure

1. Arrange numbered plastic funnels on the stand provided.
2. Insert a plug of absorbent cotton wool into each funnel
3. Add 5ml scoop of acid washed sand, and tap the funnel to level off.
4. Weigh 5g soil in a 100ml beaker. Add 5ml of sand and mix thoroughly with a glass rod.
5. The amount of sand can vary with the soil type, those with a clay or silt texture will need 10ml of sand. Add the soil/s and mixture to the funnel level off.
6. Add another 5ml scoop of sand evenly over the top of the soil/sand mixture.
7. Place a Whatman filter paper No. 42 size 7cm on top of each funnel
8. Place the funnel into the neck of a 250ml flask Add aliquot of 50ml Ammonium acetate make sure drains though before you add next aliquot.
9. Withdraw the 250mls volumetric flasks from the tip of the funnels
10. Make the flasks up to volume with ammonium acetates and mix well.

Cation exchangeable capacity –This extraction follows the total exchangeable bases extraction of the same funnels of soil and sand. The exchanged ammonium ions are replacing in the soil by leaching with IN potassium chlorite at pH 2.5

Procedure

Wash the soil with methylated spirit, 5 aliquots of 50ml each sample to make a total of 250ml. After the last aliquot of Industrial methylated spirit has leached through the funnel place in the neck of a numbered 100ml volumetric flask.
Add 5 aliquots of 25ml each of IN potassium chloride by a measuring cylinder. Make sure that all the potassium chloride aliquot drains through before adding another aliquot.
Remove the funnels from flasks and discard the soil/sand mixture.
Make up to the mark with potassium chloride and mix well

CEC Nitrogen distillation
Ammonia nitrogen can be determined by the use of a steam distilled apparatus, followed by a titration. The indicator in this method is the one required by the method to determine CEC.

Reagents

(1) 35% sodium hydroxide solution
Dissolve 35% of sodium hydroxide in about 75ml of distilled water. Allow to cool and transfer to a 100ml volumetric flask. Make up to the mark with distilled water and mix well.
(2) 2% boric acid solution
Dissolve 10g of boric, acid in about 400ml of distilled water. Transfer 10 a 500ml volumetric flask and make up to the mark with distilled water. Mix well
(3)0.01M hydrochloric acid.
Empty a vial of the concentrated volumetric solution 0.1m hydrochloric acid into a 500ml volumetric flask following the instructions the box. Make up to the mark with distilled water. Pipette 25ml of the 0.1M hydrochloric acid into 250ml volumetric flask. Make up to the mark with distilled water and mix well.

Procedure

1) Place 15ml of the 2% Boric Acid solution and 3 drops of the indicator in a 100ml conical flask. Put this under the condenser outlet, with the end in the solution.
2) Pipette 5 ml of the sample into the funnel on the apparatus. Release clip A so the sample enters the distillation chamber. Close Clip A
3) Add 5ml of 35% sodium Hydroxide in the same way as the sample, using this solution to rinse the sample into the distillation chamber.
4) Let the sample distil for about 10minute, or until there is about 50ml of liquid in the flask. Flush the apparatus twice between samples following steps 4-6.
5) Titrate the distillate with 0.1N hydrochloric acid using a 10ml burette. The end point is when the distillate changes from green to pink. Note the reading of the burette before and after the titration.

Calculation

This calculation is for 5 g of soil leached into final volume of 100ml.

For 5 ml of the sample multiply the value of the titration by 4 to give the result in mg/100g of soil.
A Procedure for determination of exchangeable Ca and Mg in the NH_4 Acetate leachate.
The exchangeable Ca and Mg ions present in the ammonium acetate leachate are determined Atomic absorption spectrophotometer

4.3 <u>Procedure for determining exchangeable K and Na in the NH_4 Acetate leachate by flame photometry.</u>

The basic of flame photometry is that certain metallic ions when ignited in a flame emit visible light of characteristic that wavelength. The amount is a measure of the concentration of that particular ion. In practice the unknown solution containing the metallic ion to be analysed is sucked through an atomizer and converted into a fine spray. The spray is thoroughly mixed with air and gas and then ignited in constant flame. An appropriate filter is inserted between the flame and a photocell, so that only light of the Wavelength characteristic of that metallic ion passes through to a photocell. An electric current is generated by a photocell in corporation to the intensity of the light of that wavelength received. The amount of current generated is registered by a galvanometer which causes a spot of light to move across a calibrated scale. The concentration of that element in the unknown solution can be determined by comparing the scale-reading with the values obtained for a set of standards. The standards used in this experiment containing known quantities of both Na and K ions together. So, by changing the filter it is possible to read of the values for Na and K for each Standard.

4.4 Determination **of exchangeable K**

i. Check that the sensitivity control of the flame photometer is turned right down (fully anticlockwise). The K filter is inserted, and the flame photometer is turned on at the mains.

ii. Turn on the compressor and adjust the air control to give an air pressure of 10 Ib/sq in.

iii. Turn on the gas and light the flame; adjust the gas control to give a flame with 10 distinct blue cones

iv. Fill one of the small beakers with the zero standard solution i.e. NH_4 Acetate, and place it in position so that a sample is drawn up into the flame photometer.

v. Adjust the set zero control until the light spot registered zero for the zero standard

vi. Remove the zero standards and insert the highest standard and then adjust the sensitivity control until the light spot registers 100.

vii. Repeat step (v) to ensure that the zero standard registers 0, if not read just the set zero, control.

viii. Record the scale values for K for each standard in turn. The concentrations of K in the standards are 0, 0.05, 0.10, 0.20, 0.25 me/100ml.

ix. Repeat steps (v) and (VI) and then insert the two unknown samples and read off the scale values.

x. Prepare the standard curve for K by plotting the scale values on the vertical axis and K concentrations in me/100ml on the horizontal axis

4.5 **Determination of Exchangeable Na**

Xi Insert the Na filter into the flame photometer

Xii Follow the steps (v), (vi) and vii).

Xiii Record the scale values for Na for each standard in turn. The concentrations of Na in the standards are 0, 0.05, 0.10, 0.15, 0.20 and 0.25 me Na/100ml.

Xiv Repeat step (v) and (vi) and then insert the unknown samples and read off the scale values

Xv Prepare the standard curve for Na by plotting the scale values on the vertical axis and Na concentrations in me/100ml on the horizontal axis.

Note: If the scale values obtained for your samples exceed 100, then you must dilute your NH_4 acetate leachate by pipetting 10ml of the leachate into a 100ml volumetric flask and making to volume with pure NH_4 acetate. Then read off the scale value for your diluted leachate. Examples for the calculation of exchangeable Ca, Mg, K and Na will be given in class.

Calculations for exchangeable Ca, Mg, K, Na and Cation exchange capacity of soils

5g of soil sample was weighed in duplicate and leached with 250ml of Ammonium acetate, pH 7.0. The leachate collected was used for the determination of exchangeable bases. The residue of the soil sample was further leached with N KCL at pH 2.5 and the leachate obtained used for the determination of total CEC in the soil sample.
10ml of the ammonium Acetate leaches reacted with Y ml of 0.0IN ETDA.
1ml of 0.0IN EDTA is equivalent to 0.01 me of Ca^{2+} ions.
If only 0.0IY me of Ca^{2+} ions are present in 10ml of NHAC leachate, then in 250ml there are

$$\frac{0.01 \; Y \times 250}{10} = 0.25 \text{ Y me}$$

Thus, since 250ml were used to leach 5g soil, there are 0.25 Y me of Ca^{2+} ions in 5g soil 100g soil contain $\frac{0.25Y}{5}$ me x 100 = 5y me Ca/100g SOIL
NB: me = ml x N
Similarly, the amount of Mg will also be calculated as above. Read off from your standard curve the concentration of K, or Na in me/100ml present in your unknown samples.
Suppose you have y me k/100ml.
Thus, 100ml contains Y me of K
250ml contains Y/100 x 250 = 2.5 Y me K,
In 5g of soil there is 2.5 Y me of K in 100g of soil there is $\frac{2.5Y}{5}$ x 100 = 50Y me/100g soil

Do the same for Na
Calculations for total CEC
$NH_3\,(g) + H_3B0_3 \qquad NH_4H_2B0_3$
Titrate the distillate with 0.0IN HCL.
1ml of the acid = 0.01 me NH^{4+} ions
X mls of 0.01 N HCL = 0.01 X me NH+ ions
If 0.01 x me NH_4+ ions are present in 5ml of aliquot
From KCL leachate, then 100mls will contain $\frac{0.1 \text{ x me x 100mlx100ml}}{5\text{ml}}$
Thus, since 100ml were used to leach 5g soil, there are
= $\frac{0.01 \text{ X me x 100ml}}{5\text{ml x 5g}}$
100g soil contain = $\frac{0.01 \text{ x me x 100ml x 100g}}{5\text{ml x 5g}}$
= 4 x me/100g
5ml of solution contains 0.01 x me of NH^{4+}
100ml (we leached with 100ml, N KCl), contain 0.01 x 100
Thus, 5g of soil contain $\frac{0.2}{5}$ x me = 4 x/100g SOIL

Ref Total Nitrogen –methods of soil analysis Part II edited Black et alia
-Laboratory methods of soil and plant analysis working manual by J.R. Okalebo et alia
soil survey manual for Tropical soils by Booklet

Chairman---Date: -------------------------------
Dept., of LARMAT

Appendix 9: Coding list for farmers' mental model of fertile soil (n=58. source: causal diagram)

Category	Representative concept	Included other concepts from farmers' answers	Share of respondents (n=58)	
			no.	Percentage
Property	Clayey texture	heavy soil, sticky soil	14	24
	Soil type is suited to the crops	grow well in this place,	9	16
	Better than coarse texture	better harvest than sandy soils	5	9
	Middle texture	loamy sand	3	5
	Loose texture		4	7
	Good root growth		2	3
	High WHC (Soil moisture)	keep wet, hold water, remain water, absorb a lot of water faster	14	24
	Good water availability	water is there, enough water, a lot of water, water is supplied continuously to the field, plenty water,	16	28
	Black colour		3	5
Location	Natural fertility	fertility is just there	8	14
	Cowshed or Forest in the past	cowshed in the past, forest in the past	3	5
	Near home		8	14
	Bottom of slope	lower place	4	7
	Moisture in subsoil	when dig see moisture	4	7
	Washing		1	2
	Easy to watering		3	5
	Near river		11	19
Management	Humus	flood deposits organic matters	2	3
	Add somethings to soils	add manure, add plant residue, add chemical fertilizer	26	45
	Soil from erosion	soil is protected	6	10
	More fertilizer/manure		1	2
	More nutrients		8	14
	Terrace construction		8	14
	Decomposition		1	2