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Sustainability of organic and non-organic smallholder farms in Kenya

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DEDICATION

To my angel mother Jane Wanjiru Kamau, all that I am or hope to be, I owe to you. You are always in my heart.

Sustainability of organic and non-organic smallholder farms in Kenya

ABSTRACT

Smallholder farms play a vital role in the quest for sustainable development, especially in sub-Saharan Africa (SSA) where livelihoods are still heavily reliant on agriculture. Current environmental and socioeconomic challenges make it necessary for agriculture to change to more sustainable production methods. Organic agriculture is rapidly increasing in the region, but there are lively debates about its sustainability, partly due to scarce and inconclusive scientific evidence. Using Kenya as a case study, this research aims to provide insights into organic agriculture as a strategy for sustainable development in SSA. To capture the complexity of smallholder farms and the diverse biophysical conditions in Kenya, data from 488 smallholder farms in two counties (Kajiado and Murang'a) were collected. A typology of five farm types was developed based on structural, functional and socio-economic aspects. The farms were categorized into: i) the wealthiest mixed organic and conventional farms, ii) wealthy certified organic farms, iii) moderately wealthy organic farms, iv) poorer conventional farms, and v) the poorest low-input-output farms. The practice of organic agriculture was linked to better access to productive assets, and higher food security and gender equity.

Sustainability assessments of a selection of the farms (n=400) were conducted using the SMART-Farm Tool based on four sustainability dimensions: good governance, environmental integrity, economic resilience, and social well-being. Results indicate that the sustainability of all farms was affected by inadequate capacity development, limited support for the vulnerable, and limited social security for farmers and farm workers, as well as lack of reliable information on farm management. Certified farms had better sustainability performance than non-certified farms in terms of higher economic resilience, greater support for workers, better use and handling of agrochemicals, higher biodiversity, and better soil and water quality. However, certified farms experienced higher yield losses and were not significantly different from non-certified farms in terms of use of organic soil amendments, water use, animal husbandry practices or profitability. Farms in Murang'a were more sustainable than those in Kajiado due to better conflict resolution mechanisms, land tenure security, soil and water conservation measures, and commercial viability. Nonetheless, farms in Murang'a showed poor animal husbandry practices, manure management, and limited credit uptake and market involvement.

Finally, due to the important role of agriculture as a major driver of land degradation in SSA, soil fertility and biodiversity were assessed for a subsample of 20 farms (10 per county). Soil fertility was measured through physicochemical indicators, and biodiversity was determined through crop residue decomposition and arthropod diversity. The results indicate a comparable performance of organic and non-organic farms regarding soil fertility. Higher biodiversity levels in organic farms indicate that organic agriculture practices do not reduce sustainability in Kenya but might have the potential to improve it, indicating a generally higher sustainability of organic agriculture. However, the lower performance of organic compared to non-organic farms in terms of yield losses has to be targeted through appropriate interventions like post-harvest technologies and soil amelioration. The results of this study provide a basis for informed decision-making, development and implementation of suitable and targeted interventions to address the sustainability gaps identified for each type of smallholder farms.

Nachhaltigkeit von ökologisch geführten und konventionellen kleinbäuerlichen Betrieben in Kenia

KURZFASSUNG

Kleinbäuerliche Betriebe sind von zentraler Bedeutung für das Erreichen von nachhaltigen Entwicklungszielen in Subsahara-Afrika, wo die Lebensgrundlage weiter Teile der Bevölkerung nach wie vor von der Landwirtschaft abhängt. Gegenwärtig zwingen umweltbedingte und sozioökonomische Herausforderungen landwirtschaftliche Betriebe zur Umstellung auf nachhaltigere Anbaumethoden, und gerade der ökologische Anbau boomt derzeit in der Region. Die Nachhaltigkeit dieser Anbaumethoden ist jedoch umstritten, da wissenschaftliche Studien hierzu nur begrenzt zur Verfügung stehen oder deren Ergebnisse unschlüssig sind. Am Fallbeispiel Kenia untersucht diese Studie ökologische Landwirtschaft als eine Möglichkeit um nachhaltige Entwicklungsziele in Subsahara-Afrika zu erreichen. Hierfür wurden Daten von 488 kleinbäuerlichen Betreiben in den Countys Kajiado und Murang'a erhoben. Der Umfang der Erhebung soll der Komplexität dieser Betriebe und ihrer biologisch-physikalischen Voraussetzungen gerecht werden. Eine Typologie wurde im Zuge dessen erstellt, welche die untersuchten Betriebe anhand von strukturellen, funktionalen und sozioökonomischen Kriterien ordnet. Dabei wurde zwischen i) den wohlhabendsten ökologischen/konventionellen und rein konventionellen Betrieben, ii) den wohlhabenden zertifizierten ökologischen Betrieben, iii) den mäßig wohlhabenden ökologischen Betrieben, iv) den einkommensschwächeren konventionellen Betrieben und v) den einkommensschwächsten extensiven, ertragsarmen Betrieben unterschieden. Ökologische Landwirtschaft wurde in dieser Studie mit einem einfacheren Zugang zu Vermögenswerten, erhöhter Ernährungssicherheit und Geschlechtergerechtigkeit assoziiert.

Eine Auswahl der untersuchten landwirtschaftlichen Kleinbetriebe (n=400) wurde anschließend mit einem SMART-Farm-Tool anhand von Nachhaltigkeitskriterien (gute Gouvernanz, ökologische Integrität, wirtschaftliche Belastbarkeit und sozialer Wohlstand) bewertet. Die Resultate dieser Untersuchung legen nahe, dass die Nachhaltigkeit aller Betriebe von unzureichenden Weiterbildungsmaßnahmen, begrenzter Unterstützung von Bedürftigen, geringer sozialer Sicherheit von Landwirten und Arbeitern sowie von einem Mangel an verlässlicher Informationen zum Betriebsmanagement beeinträchtigt werden. Zertifizierte Betriebe zeichneten sich in der Studie durch eine bessere Nachhaltigkeitsperformanz in Bezug auf die wirtschaftliche Widerstandsfähigkeit, Unterstützung der Arbeiterschaft, effizienteren Nutzung und sichereren Handhabung von Agrochemikalien, höherer Biodiversität und besserer Boden- und Wasserqualität aus. Die zertifizierten Betriebe müssen jedoch höhere Ertragsausfälle hinnehmen und unterscheiden sich nicht signifikant von nicht zertifizierten Betrieben bei der Verwendung von biologischen Bodenzusätzen, der eingesetzten Wassermenge, den Tierhaltungspraktiken sowie der Profitabilität. Landwirtschaftliche Kleinbetriebe in Murang'a haben sich darüber hinaus in der Studie im Vergleich zu den Betrieben in Kajiado als insgesamt nachhaltiger erwiesen. Als Gründe hierfür wurden in der Region ein besseres Konfliktmanagement, höhere Grundbesitzsicherheit, bessere Wasser- und Bodenschutzmaßnahmen, sowie die generell bessere wirtschaftliche Leistungsfähigkeit der Betriebe identifiziert.

Da landwirtschaftliche Nutzung ein wichtiger Faktor ist, der zu Bodendegradation in Subsahara-Afrika beiträgt, wurde in dieser Studie von einem Teil der ursprünglichen Stichprobe außerdem Daten zu Bodenfruchtbarkeit und Biodiversität erhoben. Hierfür wurden 20 Betriebe (10 pro County) untersucht. Die Bodenfruchtbarkeit wurde anhand von physikalisch-chemischen Indikatoren, die Biodiversität anhand der Zersetzung von Housing Ernterückständen sowie der im Boden

vorhandenen Arthropoden bestimmt. Die Ergebnisse dieser Studie weisen auf eine Vergleichbarkeit von ökologisch und konventionell geführten Betrieben in Bezug auf Bodenfruchtbarkeit hin. Die höheren Biodiversitätslevel der ökologisch geführten Betriebe legen jedoch nahe, dass die so geführten Betriebe dem Ziel der Nachhaltigkeit in Kenia potentiell zuträglich und nicht hinderlich sind. Den schlechteren Performanzwerten von ökologisch geführten Betrieben bezogen auf Ertragsausfälle sollte jedoch gezielt mit verbesserten Nacherntetechnologien und Bodenverbesserungsmaßnahmen begegnet werden. Die Ergebnisse dieser Studie liefern eine Basis für eine informierte Entscheidungsfindung sowie für die Entwicklung und Implementierung von geeigneten und gezielten Maßnahmen, um den Nachhaltigkeitsdefiziten für die unterschiedlichen Typen von kleinbäuerlichen Betrieben in Kenia und darüber hinaus spezifisch begegnen zu können.

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List of acronyms and abbreviations

ASAL	Arid- and semi-arid land
CA	Cluster analysis
EOA	Ecological Organic Agriculture
FAO	Food and Agriculture Organization
GDP	Gross domestic product
GoK	Government of Kenya
IFOAM	International Federation of Organic Agriculture Movements
ILO	International Labor Organization
KOAN	Kenyan Organic Agriculture Network
LD	Land degradation
MANOVA	Multivariate analysis of variance
NAAIAP	National Accelerated Agricultural Inputs Access Program
NGO's	Non-governmental organisations
OA	Organic agriculture
PAN	Pesticide Action Network
PCA	Principal component analysis
PC'S	Principal components
PGS	Participatory Guarantee System
SAFA	Sustainability Assessment of Food and Agriculture Systems
SDGs	Sustainable Development Goals
SMART	Sustainability Monitoring and Assessment RouTine
SOM	Soil organic matter
SSA	Sub-Saharan Africa
UN	United Nations

1 GENERAL INTRODUCTION

1.1 Sustainable development

Agriculture today faces the challenges of feeding a growing population while reducing its environmental impact (Seufert et al. 2012; Borrelli et al. 2017). These challenges will be more dire for Africa, where the population is expected to double by 2050 (Gerland et al. 2014; UN 2017). Particularly in sub-Saharan Africa (SSA), 20% of the people are undernourished (FAO 2017) and more than 40% (2013) still live on $1.90 or less a day in purchasing power parity terms of 2011 (World Bank 2017). Because over 65% of the population in SSA still derive their livelihoods from agriculture, mainly practiced by smallholder farmers (Salami et al. 2010; Davis et al. 2017), agricultural growth is fundamental in reducing poverty and food insecurity and for income generation (Conceição et al. 2016; World Bank 2017; Ozturk 2017). However, farming in SSA faces daunting challenges including severe land degradation as well as poor access markets, inputs, information and technology, human and financial capital. It is also constrained by low investments in agriculture, vulnerability to climate change, and over-reliance on food imports and thus increased vulnerability with respect to external market shocks and trade policies (Salami et al. 2010; Cohn et al. 2017; FAO 2017).

To address these challenges and to attain the United Nations Sustainable Development Goals (SDGs) by the year 2030 (UN General Assembly 2014), it is important to shift towards sustainability (Godfray et al. 2010). Sustainable development is one of the commonly used bases on which the agricultural and food sector are examined (Schader et al. 2014a). The classical definition of sustainable development in the Brundtland report is often used, i.e. 'development that meets the needs of the present without compromising the ability of future generations to meet their own needs' (WCED 1987). Although the definition of sustainable development, hereafter referred to as sustainability, has evolved and its precise definition is a challenge (Schaller 1993; Pretty 1995), there is agreement on the classical key dimensions of sustainability, i.e. environmental, economic and social.

1.2 Sustainability in agriculture and smallholder farms

Sustainable agricultural systems are those that positively contribute to natural, social and human capital while unsustainable systems deplete these assets. The main resource constraints to agricultural sustainability and productivity are water, soil, biodiversity and land (Pretty and Bharucha 2014). These finite resources are becoming more depleted over time. For instance, 1-6 billon ha of land are globally affected by land degradation, mainly due to human activities (Bai et al. 2008; Gibbs and Salmon 2015). Furthermore, human activities have led to a higher biodiversity loss in the last 50 years than ever before in history (MEA 2005).

The very long-term trend of land use (Figure 1.1) shows a transition from natural to other uses like intensive agriculture and to urban areas, which implies that provision of ecosystems services will become even more threatened unless the natural resource base is concurrently conserved (Foley et al. 2005). Many agricultural land-use practices reduce the ability of ecosystems to provide goods and services in the long run despite the short-term gains such as increased food production (Foley et al. 2005). Negative impacts of conventional agriculture, such as pollution of groundwater and surface water and loss of genetic diversity in plants and animals emphasize the need for a more resource-conserving agriculture (Schaller 1993).

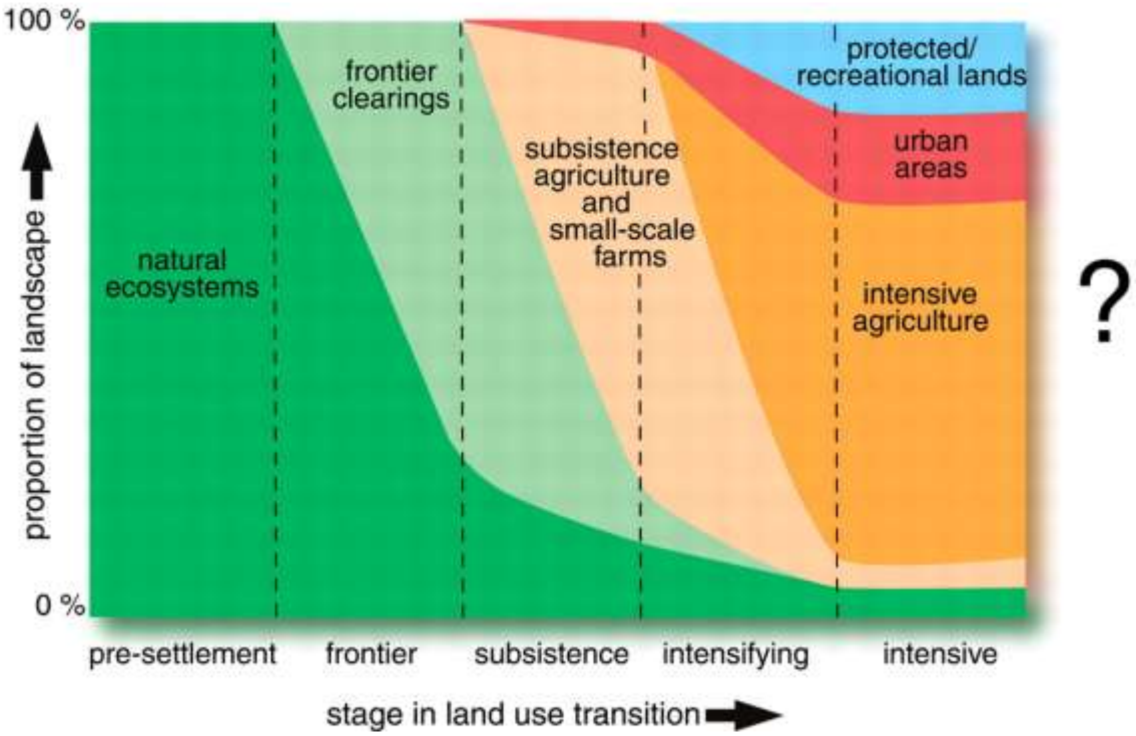

Figure 1.1 Land-use transitions. Source: Foley et al. (2005)

Smallholder farmers play a crucial role in land-use transition. Smallholder farms - defined by landholding size (Lowder et al. 2016) - constitute the majority of farms in the world, with about 500 million smallholders with farms of less than 2 ha in size accounting for 80% of all farms who cultivate about 12% of the world's 2.1 billion ha of agricultural land. Smallholders produce the bulk of the world's food and are crucial managers of natural resources. However, in SSA, around 50% of the smallholders (i.e. cultivating up to 2ha), live in absolute poverty (Altieri 2009; Salami et al. 2010; Lowder et al. 2016; Samberg et al. 2016; Cohn et al. 2017). If smallholder farms are on the path to becoming more intensive as shown by Foley et al. (2005), they should intensify in a sustainable way (Pretty and Bharucha 2014). However, at present, given the socio-economic, demographic and ecologic constraints, smallholder farms in SSA are showing a tendency towards unsustainable practices (Salami et al. 2010; Tittonell and Giller 2013; Cohn et al. 2017).

Although a concise definition of which agricultural practices are sustainable in which location and situation is not easy (Schaller 1993), there is a consensus that practices that promote (agro)biodiversity, nutrient and water-use efficiency, reduce exposure to agrochemicals, reduce soil erosion and promote other resource-conserving activities are more sustainable (Godfray et al. 2010; Sachs et al. 2010; Stellmacher et al. 2013). Since sustainability and agriculture are both multifaceted concepts, sustainable agriculture in smallholder farming involves more than conservation of the natural resource base. It involves approaches that aim to tackle the numerous challenges faced by smallholders such as limited access to productive assets and financial capital (Jayne et al. 2010; Conceição et al. 2016). However, there is a high diversity in smallholder farming systems regarding structural, functional and other socioeconomic aspects, hence there is a need to classify them in a context-specific way into more homogenous groups to support better targeted implementation of interventions (Kuivanen et al. 2016a; Kamau et al. 2018).

1.3 Organic agriculture and sustainability

Organic agriculture (OA) is frequently put forward as a more sustainable alternative to conventional agriculture. However, this notion is contested and there is uncertainty regarding the sustainability of OA. On the one hand, compared to conventional agriculture, OA is criticized for its inability to supply adequate amounts of nitrogen (N), for lower yields leading to the need for additional land for production, and for higher consumer prices. On the other hand, it has been credited for its potential to increase biodiversity, improve soils and water quality, reduce N surpluses, and to improve profitability and nutritional value (Seufert and Ramankutty 2017; Muller et al. 2017). To achieve better sustainability in agriculture, it is argued that the focus should not only be on production but also on consumption (Muller et al. 2017).

Nevertheless, although the practice of OA is still minimal with only about 1% (43 million ha) of the global agricultural land under organic production, and Africa having only about 3% of the global share (1.3 million ha), there has been a constant growth of OA in the last decades (Willer and Lernoud 2016). The African Union endorsed OA as one of the main pathways to more sustainable development on the continent, and is promoting it through the "Ecological Organic Agriculture" (EOA) initiative. In addition, increased demand for organic produce mostly for exports but also increasingly for domestic markets has also fuelled growth of OA in SSA (Bett and Freyer 2007; Niggli et al. 2016). The definition of OA by the EOA is similar to that used by the IFOAM (International Federation of Organic Agriculture Movements), and is also used in this study (Niggli et al. 2016). According to the IFOAM, 'Organic agriculture is a production system that sustains the health of soils, ecosystems and people and relies on ecological processes, biodiversity and cycles adapted to local conditions, rather than the use of inputs with adverse effects' (IFOAM 2013). In this study, the terms EOA and OA are used synonymously. Therefore, although OA is still in its infancy in SSA, it is essential to evaluate and monitor its sustainability within smallholder farming systems given the vital role of smallholders for land use and the livelihoods of the majority of the people in this region.

1.4 Sustainability assessment

An understanding of the impact of agricultural systems on sustainability is indispensable for making decisions on how to reduce negative impacts of agriculture on natural ecosystems, to improve food security and to reduce poverty (de Olde et al. 2016a). Sustainability assessment based on comprehensive frameworks that integrate the major dimensions of sustainability (i.e. economic, social and environmental) can help in making such difficult decisions (Angevin et al. 2017). Indicators are used in sustainability assessments to evaluate and monitor farms and farming systems.

Many indicator-based tools have been developed to assess sustainability. However, these tools vary widely in purpose (e.g. research, extension, policy and planning), assessment level (e.g. product/supply chain, farm), dimension (e.g. environmental and/or economic and/or social), intended user, assessment approach (e.g. self-assessment, external auditor), and specificity level (e.g. sector, country or region specific) (Schader et al. 2014a; de Olde et al. 2016c). Due to this diversity in these sustainability assessment tools, comparability of data and results is a challenge.

Although one-size-fits-all solutions are not possible, there is a consensus regarding the need for harmonizing approaches, criteria and indicator sets, as well as increased transparency to enhance the comparability of different sustainability assessment methods (Dantsis et al. 2010; Sachs et al. 2010; Schader et al. 2014a; de Olde et al. 2016a, c).

1.5 Agricultural sustainability in Kenya

Like other SSA countries, development in Kenya is closely associated with agriculture. The agricultural sector is the main livelihood source for more than 75% of the Kenyan population. However, nearly 50% of the population lives poverty and is food insecure. Moreover, the majority of the people live in rural areas and practice smallholder farming, and high levels of unemployment exist in the country, particularly among the youth (Krishna et al. 2004; ILO 2016; WFP 2016). About 60% of the around 50 million people in Kenya are 24 years and younger, while only 45% are above the age of 60 according to the recent World Population Prospects report (UN 2017). In the same report, Kenya's population is projected to nearly double to about 95 million by 2050.

Against this background, it appears that smallholder agriculture can play a vital role in sustainable development in Kenya. However, like other countries in SSA, the smallholders face many challenges, such as limited access to capital and productive resources (GoK 2009; Salami et al. 2010; Amudavi et al. 2014; Jouzi et al. 2017). Additionally, land degradation affecting over 12 million of the Kenyan population mainly due to declining soil fertility, soil erosion, deforestation and desertification is a major challenge (Mulinge et al. 2016). Furthermore, there is an over-reliance on rainfed agriculture even though Kenya is predominantly dry with more than 80% of the landmass classified as arid- and semi-arid (ASAL) with less than 1100 mm annual rainfall. The remaining landmass (>20%) is classified as humid to semi-humid with 600-2700 mm rainfall annually (Sombroek et al. 1982; Ngigi 2002; Alila and Atieno 2006; GoK 2009). Farming in ASAL regions is threatened by water scarcity and erratic weather events that are likely to be exacerbated by climate change (Njiru 2012; Oguge and Oremo 2018).

An important step towards making agriculture more sustainable is evaluating the multiple effects of different farming systems (Godfray et al. 2010; Sachs et al. 2010). In addition, due to the role that farm management plays in soil fertility and nutrient availability (De Jager et al. 2001; Adamtey et al. 2016) and the positive linkage between soil fertility, plant productivity and biodiversity (Delgado-Baquerizo et al. 2017), it is important to evaluate the effects of different farm management systems, including organic and non-organic, on soil health. However, assessments should always take into account diversity in agricultural systems and biophysical factors (Chopin et al. 2017)

1.5.1 Aim and objectives

Against this background, the main objectives of this study were the following:

1. To characterize smallholder farms practicing organic and non-organic agriculture in the counties Kajiado (ASAL region) and Murang'a (humid to semi-humid region) in Kenya, and to identify factors driving variability between organic and non-organic farms
2. To assess the sustainability of smallholder farms in Kajiado and Murang'a and determine possible differences in sustainability performance between the smallholder farms in the two counties and across the identified farm types and the organic certified and non-certified farms among these.
3. To evaluate and compare soil fertility and soil biodiversity by examining soil physicochemical properties as well as biodiversity of epigeal arthropods and ecological activity of soil microorganisms in organic and non-organic smallholder farms in Kajiado and Murang'a

1.5.2 Structure of the thesis

The thesis is structured according to the above objectives. Chapter 2 introduces a typology of smallholder farms, the distinguishing factors of the different farm types, and their distribution in the sampled counties. The chapter highlights the important role of typology construction in understanding current practices and needs of smallholders, as well as systematic targeting of development interventions in a needs oriented way. Chapter 3 presents sustainability assessments of smallholder farms, identifies patterns and differences in sustainability performance with respect to the farm types identified in the typology, certified organic and non-certified farms and the two counties. Gaps in sustainability and their implications are also discussed. Chapter 4 presents an evaluation of soil fertility using physicochemical indicators and biodiversity based on evaluation of the abundance, richness and diversity of soil arthropods as well as the decomposing activity of soil micro-/mesofauna and microflora for selected farms. Chapters 5 concludes the dissertation by providing a synthesis of the results and presents an outlook for future research.

1.6 Study area

The study was conducted in the counties Kajiado and Murang'a in Kenya (Figure 1.2). Kajiado is located in south-western Kenya in the ASAL region. It covers an area of almost 22,000 km^2, with a population of nearly 700,000 inhabitants and a population density of about 31 people per km^2 in 2011 (KNBS 2015a). It lies between 36° 5' and 37° 5' East and 1° 0' and 3° 0' South. Altitudes range between 500 m.a.s.l. at Lake Magadi and 2,500 m.a.s.l. in the Ngong Hills. Annual precipitation varies with altitude and ranges from 300 mm to 1250 mm. Lower areas are dominated by black clayey variants of 'black cotton' (Vertisols) soils that are poorly drained and prone to waterlogging though with high chemical fertility, while the higher areas have clay loams, sandy soils, ash and pumice soils. The county is considered to have low agricultural potential. The main land uses include pastoralism, wildlife conservation, rain-fed and irrigated crop farming as well as livestock farming. Farmers there produce predominantly food crops such as potatoes, vegetables and cereals (Jaetzold et al. 2006; KCDP 2013; Ogutu et al. 2014).

Murang'a is located in central Kenya in the humid to semi-humid region. It covers a total area of about 2,500 km^2 with a population of 940,000 and population density of about 368 people per km^2 in 2011 (KNBS 2015b). The county is located between 0° 34' and 1° 7' South and 36° and 37° 27' East. Altitudes range between 914 and 3,353 m.a.s.l. with a humid to semi-humid climate. Annual rainfall is bimodal and up to 2700 mm. Soils vary between those formed from volcanic and tectonic activities and soils such as Andosols and Histosols to strongly weathered Ferrasols (Jaetzold et al. 2006; MCDP 2013). Erosion is a major problem and negatively impacts top soil fertility and consequently crop yields. The main land-use types are crop farming and animal husbandry. Smallholder farmers usually cultivate tea, coffee, avocado, macadamia, root tubers, cereal, pulses crops as well as fruits and vegetables (Muchena and Gachene 1988; Ovuka 2000a; MCDP 2013).

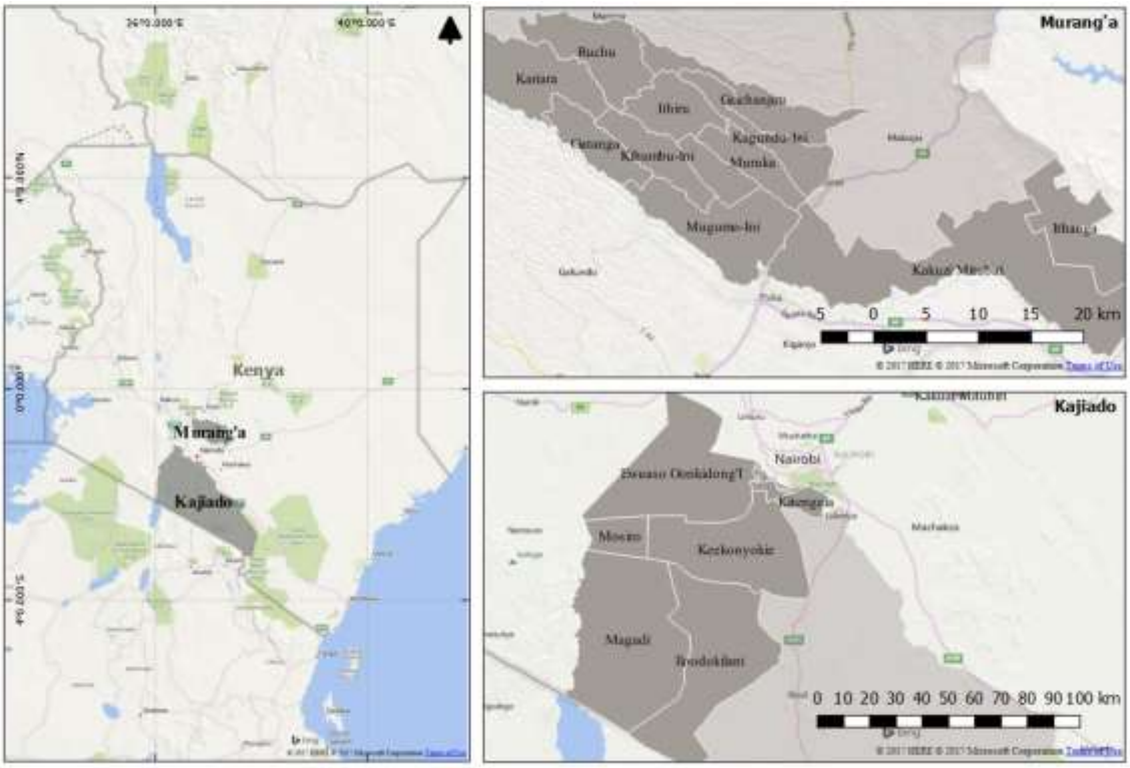

Figure 1.2 Map of Kenya (left) showing the location of Kajiado and Murang'a counties and their respective wards (right).Data source(GADM 2015)

2 ORGANIC AND CONVENTIONAL AGRICULTURE IN KENYA: A TYPOLOGY OF SMALLHOLDER FARMS IN KAJIADO AND MURANG'A COUNTIES[1]

2.1 Abstract

Understanding the diversity of smallholder farms is key for the development of [2]interventions, strategies and policies aimed at addressing the numerous challenges these farmers face as well as for those shaping the future of smallholder farming in Kenya, Africa and beyond. In this study, we developed a typology for smallholder farms in Kenya using survey data from 488 farm households in Kajiado and Murang'a counties. Multivariate statistical techniques (principal component and cluster analyses) were used to group farms into five types differentiated by household characteristics, resource endowment, cropping practices, social networks, access to information, dietary diversity and gender equity. Types 2, 3 and 5 were mostly market oriented, possessed high to medium levels of wealth and had strong social networks. Types 3 and 5, however, mainly practiced organic agriculture while Type 2 farms included organic and non-organic cultivated areas. Types 1 and 4 were characterized by low to medium levels of wealth, maintained poor social networks and had low adherence to organic agriculture practices. Yet, while Type 4 farms mainly practiced conventional market-oriented agriculture, farms of Type 1 could be defined as organic-by-default and were self-subsistent. The majority of the surveyed farms belonged to Type 2, i.e. the wealthiest group of farmers and mostly located in Kajiado county. Murang'a county was dominated by farms of Type 5 practicing mainly certified organic agriculture. Overall, the practice of organic agriculture was associated with higher agricultural income, legal ownership of land, older household heads, larger household sizes, stronger social networks, higher access to information, more diverse diets and higher levels of gender equity. In contrast, poorer, younger and less well-connected farmers were less involved in organic agriculture. The results of this study may help to increase efficiency in the

[1] This chapter has been published as Kamau et al. (2018), J.Rural Studies. 57, 171-185

implementation of pro-poor and organic agricultural interventions, strategies and policies on the ground and to shape policy instruments accordingly.

2.2 Introduction

Smallholder farmers are the pillar of the economies of Kenya and other sub-Saharan African (SSA) countries that are heavily reliant on agriculture (Altieri 2009; GoK 2009; Salami et al. 2010; Davis et al. 2017). In Kenya, smallholder farms with an area ranging from 0.2 to 3 ha are the source of more than 70% of the country's total agricultural produce. In a country where the agricultural sector is responsible for approximately 26% of the gross domestic product (GDP), and 18% of formal and 60% of informal employment in rural areas, the role of smallholder farmers is vital (GoK 2009). According to different estimates, almost 50% of the population of Kenya lives in poverty. The majority of the poor live in rural areas where there are high levels of food insecurity. In addition, over 65% of the Kenyan population are between 18 and 35 years, and make up over 50% of the unemployed in the country (Krishna et al. 2004; ILO 2016; WFP 2016).

On the one hand, agricultural growth has been recognised for its capacity to reduce poverty and food insecurity in SSA (Salami et al. 2010; von Braun 2010; Dethier and Effenberger 2012), which is essential to achieve the Sustainable Development Goals (SDGs) (UN General Assembly 2014). On the other hand, hundreds of millions of smallholder farmers continue to face serious challenges such as poor and declining soil fertility leading to large yield gaps for almost all crops, and limited access to financial capital, markets, land, inputs, information and technology. Pre- and post-harvest crop and animal losses due to pests and diseases are still high (GoK 2009; Salami et al. 2010; Tittonell and Giller 2013). In addition, because many African countries rely on food imports, they are vulnerable to external influences such as price fluctuations and trade barriers (WFP 2016). There is a general consensus that for most of the countries in SSA, sustainable development will largely depend on improving agricultural productivity as well as the welfare of smallholder farmers (Salami et al. 2010; Dethier and Effenberger 2012).

The practice of organic agriculture (OA) is growing among smallholder farmers in SSA and has recently received special attention from policy makers and development experts. It is perceived as a pro-poor and sustainable agricultural production model and therefore promoted as one way to deal with the persistent problems of food insecurity as well as other challenges facing smallholder agriculture in SSA (Bett and Freyer 2007; Niggli et al. 2016). However, smallholder farmers differ in structural aspects such as financial resources, information access and asset availability and allocation as well as in functional aspects such as agricultural production objectives, livelihood strategies and their dynamics (Tittonell et al. 2010; Pacini et al. 2014; Kuivanen et al. 2016a), diversification approaches (van de Steeg et al. 2010) and other socio-economic aspects (Bidogeza et al. 2009). Given the heterogeneity of smallholder farmers in SSA, any effort aimed at addressing their challenges needs to begin with an understanding of this complex diversity.

One way of addressing the diversity of smallholder farms is classifying them based on their similarities into homogenous groups, i.e. farm types (Kostrowicki 1977; Kuivanen et al. 2016a). Farm typologies help to identify appropriate and type-specific innovations, to scale them up and to investigate their outcomes (Signorelli 2016). For instance, farm types have been created for increasing the general applicability of recommendations for farm improvement (Köbrich et al. 2003; Chikowo et al. 2014), identifying reasons for low technology adoption (Bidogeza et al. 2009), supporting policy design, better targeting of agricultural novelties and household resource allocation (Tittonell et al. 2010), as well scaling-up of best-fit options (Alvarez et al., 2014).

One approach for classifying smallholder farms is the consideration of variables of the whole farming system (i.e. household, cropping and livestock systems) as well as their relationship with the ecological, economic and social outside contexts (Alvarez et al. 2014). Variables that have been used in typology studies in SSA include those on household characteristics like age, education and literacy mainly of the household head, and the size of the smallholder household. Resource endowments in terms of availability of land, livestock and other agricultural assets, labor (non-/off-farm versus on-farm), capital (i.e. income, credit access), technology and capacity to invest, are the most common variables of categorising farms. Environmental variables used in typologies include soil and water conservation, land use and management as well as cropping practices. Others variables such as production orientation (i.e. market, self-subsistence), food security and gender equity have also been used in typologies (Shepherd and Soule 1998; Tittonell et al. 2005, 2010; Bidogeza et al. 2009; van de Steeg et al. 2010; Giller et al. 2011; Sakané et al. 2013; Pacini et al. 2014; Signorelli 2016; Kuivanen et al. 2016b, a).

A number of publications used different methods to categorise smallholder farms in Kenya. Shepherd and Soule (1998), for example, grouped farmers in Western Kenya based on their resource endowment and constraints. Tittonell et al. (2005a, 2005b) identified farmer classes based on resource endowment, production orientation, farming constraints and other socioeconomic factors. In the same region, similar criteria of smallholder farm categorization were also used by other researchers (Valbuena et al. 2008; Giller et al. 2011; Mutoko et al. 2014). Household and location factors were used to categorise farmers across various other regions in the Kenyan highlands (van de Steeg et al., 2010). Sakané et al. (2013) grouped smallholder farmers in wetlands in the Mount Kenya highlands of Nyeri North and Laikipia West based on their livelihood strategies and production orientation.

All of the typology studies mentioned here were carried out in the humid and semi-humid highlands of Kenya with an annual rainfall from 600 to 2700 mm. However, more than 80% of the land in Kenya is classified as arid and semi-arid (ASAL) with an annual rainfall ranging from 150 to 1100 mm (Sombroek et al. 1982; GoK 2009). To the best authors' knowledge however, no published study has build a typology of smallholder farms in the ASAL regions of Kenya. To capture these two distinct climatic categories, farms from two counties in Kenya were selected for this study, i.e. one humid to semi-humid and one arid to semi-arid county. These counties were also selected due to their proximity to the capital Nairobi where the main market for agricultural produce is located. While studies on smallholder farm typologies of the Kenyan highlands are abundant, the contribution of this study lies in the inclusion of smallholder farms in the ASAL region and comparing them to those of the humid to semi-humid highlands. This study also attempts to provide relevant knowledge on factors driving variability in smallholder farms as well as those that set apart smallholder farms practicing OA from the rest in order to better contextualize and support policy discussions on OA as well as on other agriculture interventions and development strategies in Kenya.

The importance of improving productivity in agriculture and the welfare of smallholder farmers to sustainable development in SSA is undisputed. However, the complexity of smallholder farms poses a threat to the effectiveness of any efforts to achieve this. Past interventions by donors, government and other stakeholders have not fully succeeded in this regard, given the persistent poor productivity and wellbeing of smallholder farms. Typologies of these farms that take into account their complex heterogeneity as well as heterogeneity of their biophysical environment can be a first step to target interventions such as the EOA initiative more effectively. This in turn can contribute to improving their productivity, ultimately contributing to efforts seeking to alleviate of poverty, food insecurity and unemployment particularly in rural areas in Kenya and beyond.

Typology development should be guided by the research objectives, questions and characteristics of the study area (Duvernoy 2000; Köbrich et al. 2003). This study sought to answer the following two research questions: 1) Which types of smallholder farms can be identified, which factors drive their variability and how are they distributed between the two case counties? 2) What are the main drivers of variability between smallholder farms applying OA and those that do not? To answer the research questions we applied cluster analysis (CA) to the output of a principal component analysis (PCA), a technique known from many other similar studies (Bidogeza et al. 2009; Tittonell et al. 2010; Sakané et al. 2013; Mutoko et al. 2014; Kuivanen et al. 2016b, a).

Organic agriculture in Kenya

Organic agriculture started in Kenya in the early 1980's as an initiative of non-governmental organizations (NGOs), commercial companies as well as faith- and community-based organizations. It has been suggested that OA is associated with many benefits such as poverty reduction, enhanced food security and gender equity, adaptation to climate variability, access to markets especially through export trade, and provision of other social as well as environmental benefits (Bett and Freyer 2007; African Union 2011; Amudavi et al. 2014; Ayuya et al. 2015; Chiputwa and Matin 2016; Niggli et al. 2016; Ndukhu et al. 2016). Like in other SSA countries, the OA sector in Kenya has developed without formal regulation.

Currently, however, the sector is under legislation through the "Ecological Organic Agriculture" (EOA) initiative by the African Union. This initiative seeks to mainstream OA into national agricultural production systems in Africa by 2025 as a development pathway for the continent to improve agricultural productivity. The definition of the EOA is similar to that used by the IFOAM to describe OA, and is also used in this study (Niggli et al. 2016). According to the IFOAM, 'Organic agriculture is a production system that sustains the health of soils, ecosystems and people and relies on ecological processes, biodiversity and cycles adapted to local conditions, rather than the use of inputs with adverse effects' (IFOAM 2013). In this study, the terms EOA and OA are used synonymously.

Organic and non-organic smallholder farmers in Africa represent a number of different groups. Using a classification of smallholder farms in SSA by Bennett and Franzel (2013), that was based on intensity of use of agrochemicals versus use of soil nutrient and pest and diseases management practices, the farmers in Kenya can be grouped into five categories. These include the following: organic certified, organic uncertified, mixed organic-conventional, conventional and organic-by-default farmers. On the one hand, the certified organic farmers market products produced according to specified and verified standards that adhere to the general OA principles. On the other hand, the uncertified organic farmers adhere to many principles of OA, but are not formally certified as OA. Badgley et al. (2007) argued that OA in SSA had been erroneously compared to this subsistence low-input agriculture that is resource constrained (Badgley et al. 2007). The group termed as organic-by-default consists of a low-input low-output system characterized, lack or limited soil conservation or pest and disease management practices. The conventional farmers use agrochemicals and other conservation measures but in varied levels of intensities, while the mixed organic-conventional have less usage of agrochemicals and higher usage of soil and other conservation measures (Bolwig et al. 2009; Bennett and Franzel 2013).

There has been a rapid growth of the import of organically produced agricultural products from developing countries to developed countries, especially to the European Union (EU), North America and Japan (Barrett et al. 2001b; Niggli et al. 2016). There is also a growing demand for organic produce in the East African region attributed to improved living standards especially in urban areas and changing food preferences triggered by food safety, among other concerns (Ayuya et al. 2015; Ndukhu et al. 2016). Organic certification is seen as a way to reduce economic barriers for trading organic products by enabling access to high priced markets that reward them for the use (or non-use) of certain production systems and methods (Niggli et al. 2016; Schwindenhammer 2016).

In Kenya, organic produce destined for the export market is normally certified according to international standards of certification organizations such as Soil Association (UK), Ceres (USA), and IMO (Germany). Local East African certification resulted from a collaborative effort of IFOAM and other national organic initiatives like the Kenya Organic Agriculture Network (KOAN) and its equivalents in Tanzania (TOAM) and Uganda (NOGAMU), which created the East Africa Organic Product Standard (EAOPS), a regional certification standard for East Africa. The same initiative led to the formation of participatory guarantee systems (PGS), which are quality assurance systems built on social networks with emphasis on producer participation and are an alternative to third-party certification. In Kenya, PGS are mainly organized by groups of farmers of organic products under the guidance and support of KOAN. Farmer groups organized as PGS in Kenya are certified by Encert, which is a third-party certification body following EAOPS standards (Katto Andrighetto 2013; Ayuya et al. 2015; Schwindenhammer 2016).

2.3 Materials and Methods

2.3.1 Sampling design

A multi-stage sampling procedure was applied to select counties, sub-counties and farmers. The study was conducted at farm household level. A sampling of farmers was done after preliminary field visits to several counties in Kenya. Two counties, namely Kajiado and Murang'a, were finally selected through purposive sampling based on the general presence of certified organic farmers as well as climatic heterogeneity. The departments of agriculture of each county provided a reliable source to identify smallholder farmers, while contacts provided by KOAN provided lists of certified organic smallholder farmers registered with them. Since the size of certified organic farmers varied across the counties and sub-counties, and to ensure that every farmer had an equal chance of being included in the sample, farmers were selected through the Probability Proportional to Size (PPS) sampling method. Using this procedure, approximately 33% of the certified organic farmers (n=180) and 66% of the non-certified farmers (n=345) were randomly selected.

The surveyed certified organic farmers in Kajiado mainly belong to a PGS groups under the Ngong Organic Farmers Association (NOFA). The NOFA uses the EAOPS as a basis, albeit simplified to an internal standard, and hence they do not have full compliance to the standard. They are self-regulated and monitored with support from the KOAN and sell their produce for a premium price at organized markets in Nairobi or at the prevailing market prices at local markets (Katto Andrighetto 2013). The smallholder organic farmers in Murang'a are predominantly certified according to EU standards by international certification bodies such as the Soil Association (UK), IMO (Germany) and EcoCert (France). Private companies who have contractual arrangements with farmers facilitate the certification of farms. These companies finance the certification process aid in the OA transformation of farms through training, labor hiring for harvesting, and buying their products at a premium price above the prevailing market prices.

2.3.2 Data collection

Empirical data for this study was collected in 2015 through a semi-structured questionnaire, which was pre-tested earlier. Interviews were face to face with the heads of the farm household or, in their absence, with the most senior member of the farm household. The questionnaire included questions on household demographics such as age, occupation, household size, education and income, land tenure rights, livestock ownership, crop production practices and input use, gender equity, dietary diversity, access to credit and information, social networks and asset ownership. The term social networks was used synonymously with group membership representing the membership of a farmer in a cooperative union, crop or seed producer and marketing cooperative, farmers' association, women and youth association, religious association, savings and credit group or any other group of any member of the household. The survey captured a total of 523 smallholder farm households, i.e. 254 in Murang'a and 269 in Kajiado county. The semi-structured questionnaire was administered using Open Data Kit (ODK) (Hartung et al. 2010) installed on Android tablets and administered by trained enumerators. The data were analysed with STATA (version 13, StataCorpLP, TX, USA), R (version 3.3.1) and Microsoft Excel.

2.3.3 Multivariate data analysis

Prior to categorization, several variables were generated from a consolidation of various items from the questionnaire data. Livestock numbers (tropical livestock units, TLU) were estimated using the conversion factors by Jahnke (1982), where one TLU represents 250 kg live weight. Standardised indices were created for gender equity, dietary diversity and farm productive assets using PCA. The gender equity index was constructed from variables concerned with gender equity in financial decision-making and control over resources as well as sharing of household responsibilities based on 5-point scales (1 = Strongly agree to 5 = Strongly disagree) and 2-point scales (1= Yes, 2= No). The dietary diversity index was based on 30-day recalls concerned with the frequency of intake of major food items in different categories including cereals, tubers, vegetables, fruits, pulses, sugars, oils, meat/fish and milk products spread over different time scales in the previous month. A longer reference period has been argued to be better to determine dietary patterns than 24-hour recalls (Ng'endo et al. 2016). This dietary diversity index is similar to the Dietary Diversity Score (DDS), which estimates diversity in diets and represents the number of certain food groups consumed by an individual or a household (Kennedy et al. 2011).

The dataset with 43 variables (Table 2.1) represents the output of the farm survey designed to capture the whole farming system and its interaction with the outside context. Outliers were defined based on the threshold of 1.5 quartiles above the upper quartile or below the lower quartile, and mostly removed from the dataset prior to further analysis (Hair et al. 2010). However, some outliers were retained as they were deemed sufficiently grouped together to form a farm type (Alvarez et al. 2014). This reduced the dataset from the original 523 to 488 entries. The cluster analysis based on PCA outputs was mainly done according to the method of Alvarez et al. (2014). A functional typology of smallholder farms developed for categorising farms in Kenya by Tittonell et al. (2005a, 2005b) was partly used as a conceptual basis for categorization in this study. The typology was developed based on the outputs of PCA and cluster analyses in R (version 3.3.1) using the ade4 package (Mangin et al. 2012).

PCA can be applied to reduce the multivariate dataset of farm variables to non-correlated principal components (PCs). In this case, however, we used loadings of all variables for the most important PCs as variables for the cluster analysis. Important PCs were selected if the cumulated percentage of explained variability accounted for 90% or more of the total variance (Hair et al. 2010). The Kaiser criterion, which suggests the retention of all PCs with eigenvalues greater than unity, was first considered but given that this criterion has been argued to be less accurate if the number of variables is greater than 30 and a sample size smaller than 250 (Field 2011), we decided against it. In addition to this, correlations among the variables and the PCs were examined (Appendix A). In this study, only loadings greater or equal to 0.03 were considered for interpretation purposes given that the sample size exceeded 300 (Stevens 2002; Field 2011).

Hierarchical agglomerative cluster analysis according to Ward's method was used to group the farms into homogeneous types based on the variable loadings of the three retained PCs from the PCA (Ward 1963). The Ward method initially treats each observation as a separate cluster and merges the two most similar ones in a stepwise process. This procedure continues until all the observations are merged into one single cluster (Kuivanen et al. 2016a). The interpretation of distinct farming types is based on the graphical results from the PCA and cluster analysis and statistical calculations of the mean differences between each cluster and the rest (Alvarez et al. 2014).

Table 2.1 Summary statistics for variables used in categorizing farm households.

Variable (n=488)	Unit	Mean	Std. Dev.	Min	Max
Household					
Age of household head (hhh)	Years	54	15	20	94
Total household (hh) size	Number	5	3	1	19
Total years of education of hhh	Years	9	4	0	19
Ability of hhh to read and write	% hhs'[a]	0.88	0.33	0	1
Household labor					
Members working fulltime on-farm	Number	1.3	0.9	0	6
Members working part time on-farm	Number	1.4	1.6	0	9
Members working fulltime off-farm	Number	0.7	1.4	0	10
Land size and use					
Land legally owned (acres)	ha[b]	0.84	0.83	0.00	5.26
Land rented in (acres)	ha[b]	0.07	0.17	0.00	1.01
Legally owned land cultivated (acres)	ha[b]	0.59	0.65	0.00	4.45
Rented land cultivated (acres)	ha[b]	0.06	0.15	0.00	0.81
Cropping practices					
Pure stands only	% hhs'[a]	0.15	0.36	0	1
Intercropping only	% hhs'[a]	0.76	0.43	0	1
Both pure stands and intercrop	% hhs'[a]	0.09	0.29	0	1
Organic farming practices of households					
Record keeping	% hhs'[a]	0.29	0.46	0	1
Mulching and cover cropping	% hhs'[a]	0.58	0.49	0	1
Use of organic soil additions	% hhs'[a]	0.94	0.24	0	1
Lack of use of any organic soil additions	% hhs'[a]	0.1	0.3	0	1
Use of bio-pesticides	% hhs'[a]	0.18	0.39	0	1
Intercropping with legumes	% hhs'[a]	0.68	0.47	0	1
Crop rotation	% hhs'[a]	0.63	0.48	0	1

Table 2.1 continued

Variable (n=488)	Unit	Mean	Std. Dev.	Min	Max
Use of synthetic pesticides	% hhs'[a]	0.28	0.45	0	1
Use of mineral fertilizers	% hhs'[a]	0.42	0.49	0	1
Access to credit and information					
Accessed credit in the last season	% hhs'[a]	0.09	0.28	0	1
Accessed credit in the last 2 years	% hhs'[a]	0.1	0.3	0	1
Accessed information on crop production	% hhs'[a]	0.5	0.5	0	1
Accessed information on input use	% hhs'[a]	0.3	0.46	0	1
Knowledge and practice of organic agriculture					
Heard of organic agriculture	% hhs'[a]	0.74	0.44	0	1
Practice of certified organic agriculture	% hhs'[a]	0.32	0.47	0	1
Group membership (social networks)	% hhs'[a]	0.43	0.5	0	1
Income					
Crop income	Av $ p.a[c]	208	112	0	297
Livestock income	Av $ p.a[c]	164	118	0	297
Income from other agricultural employment	Av $ p.a[c]	27	47	0	297
Income from non-agricultural employment	Av $ p.a[c]	72	106	0	297
Business income	Av $ p.a[c]	87	116	0	297
Remittance income	Av $ p.a[c]	26	61	0	297
Pension income	Av $ p.a[c]	32	70	0	297
Income from other sources	Av $ p.a[c]	58	101	0	297
Crop gross margin	$ p.a	298	571	-1807	3870
Ownership of productive assets (asset index)	%	16.7	11.8	1.5	70.0
Dietary diversity (dietary diversity index)	%	40.4	19.2	0.5	94.5
Livestock ownership in TLU[d]	Tlu	2.5	6.2	0	70
Gender equity (gender index)	%	74.6	13.4	14.8	96.9

[a] *Percentage share of households in a yes/no scale who answered yes*
[b] *Conversion factor of 1 ha approximately 2.47 acres*
[c] *Average income in the household per annum (p.a). Income variable in an 8-item and 5-item Likert scale (1 = < 25USD, 5 = > 297USD), on different sources of farm household income, and average in each class calculated and converted at a rate of one USD for approximately 101 Kenya Shillings (KES).*
[d] *Tropical Livestock Unit (TLU): livestock conversion factors based on (Jahnke 1982)*

2.4 Results

Summary statistics for all smallholder farmers showed that, on average, the household heads were relatively old (54 years), with family sizes of five members and nine years of education, which represents lower secondary schooling level in Kenya, and that they owned less than one hectare of land (Table 2.1).

Three PCs were derived from the PCA analysis explaining 90% of the variability in the dataset. The first PC explained the greatest variance of about 82% (Table 2.2). Variables relating to knowledge and practice of organic farming, group membership, information access, crop and livestock income, asset ownership, ownership and cultivation of legally owned land, agricultural employment and pension income were closely related to PC1. Therefore, PC1 appeared to explain agricultural wealth and OA (Figure 2.1 A and C, Appendix A). PC2 was associated mainly with variables of rented land and its cultivation, age, education and literacy levels of the household head, use of synthetic pesticides, access to credit, and non-agricultural income. PC2 appeared to explain non-agricultural wealth and conventional farming (Figure 2.1. A, Appendix A). PC3 correlated with variables related to cropping systems (mainly intercropping) and record keeping (Figure 2.1 C, Appendix A). Variables like TLU, part-time on-farm labor, use of mineral fertilizer and other income sources seemed not to provide much additional information for the PCA but were retained to fulfill the criteria to explain 90% of the variability of the farms (Figure 2.1 A and C).

The results from the hierarchical clustering procedure suggested a five-cluster cut-off point shown in the clustering dendrogram, and a bar plot showing maximum dissimilarity among clusters with increasing grouping of observations (Figure 2.3). This led us to grouping the farm households into five broad farm types (Figure 2.1 B and D), which will be described according to their characteristics in the following sections. However, variables of part-time on-farm labor and use of mineral fertilizer were excluded from defining the farm types as there were no significant differences ($p<0.05$) among the five types of farms (Table 2.3).

Table 2.2 Selected principal components with their respective eigenvalues and percentage variance explained using PCA.

Principal component	Eigenvalue	Variance explained (%)	Cumulative Variance %
1	4.11	82.1	82.1
2	3.14	4.6	86.7
3	2.62	3.7	90.4

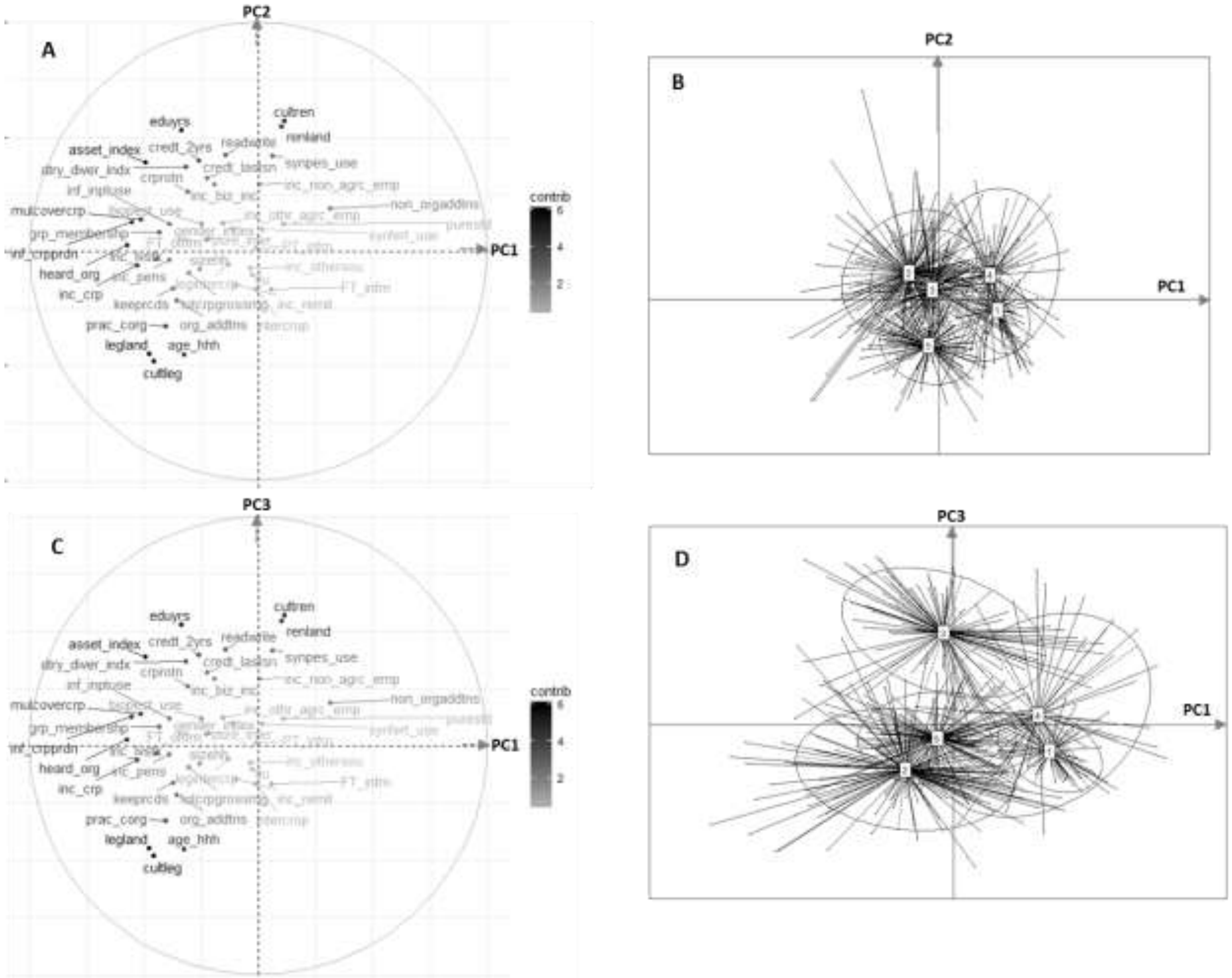

Figure 2.1 Output of PCA and cluster analysis: correlation circles (A and C) and farm types 1-5 (B and D) in the planes PC1-PC2, PC1-PC3. The shading intensity of the variable names darkens with increase in the contribution of the variable to the PCs.

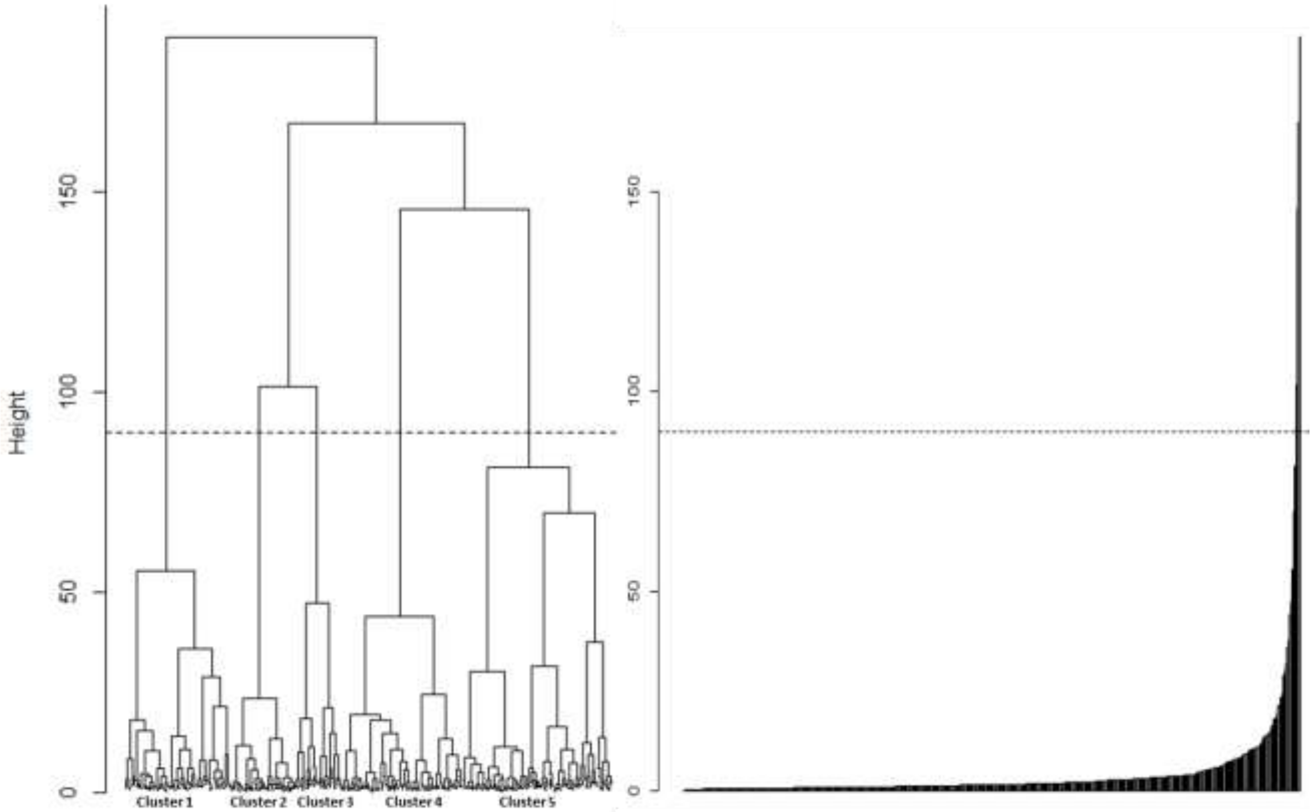

Figure 2.3 Dendrogram (left) and associated bar plot (right) illustrating range of cluster solutions resulting from Ward's method of cluster analysis. Dotted line shows selected cut-off points, which gave a 5-cluster solution (Types 1-5). Vertical axis represents distance or 'height' between the clusters at each stage

Table 2.3 Distribution of characteristics by farm type

	Type 1 n=65	Type 2 n=150	Type 3 n=106	Type 4 n=46	Type 5 n=121
Variable					
Age of household head (hhh)	50**	53	55	43**	61**
Total household (hh) size	4**	5	5	5	6*
Total years of education of hhh	8.1**	11.6**	10	8.7	7.2**
Share of hhhs that can read and write	0.16	0.19**	0.18**	0.16	0.13**
Number of hh members working fulltime on-farm	1.5	1.0**	1.3	1.5	1.5**
Number of hh members working part time on-farm	1.2	1.3	1.6	1.7	1.4
Number of hh members working fulltime off-farm	0.4**	1.0**	0.6	0.5	0.7
Size of land legally owned (ha)	0.33**	0.96	0.64**	0.79	1.17**
Size of land rented in (ha)	0.06	0.12**	0.04**	0.13*	0.01**
Size of legally owned land cultivated (ha)	0.23**	0.66	0.43**	0.65	0.81**
Size of rented land cultivated (ha)	0.05	0.10**	0.03**	0.13**	0.01**
Share of households (hhs) keeping records	0.01**	0.05	0.08**	0.03**	0.07*
Share of hhs planting pure stands only	0.00**	0.00**	0.11**	0.03	0.00**
Share of hhs intercropping only	0.19**	0.18**	0.01**	0.14	0.19**
Share of hhs planting both pure stands and intercropping	0.00**	0.01**	0.07**	0.02	0.00**
Share of hhs practicing mulching and cover cropping	0.04**	0.14**	0.12**	0.07**	0.11
Share of hhs using organic soil additions	0.19**	0.19**	0.19**	0.06**	0.19**
Share of hhs not using ANY organic soil additions	0.00**	0.00**	0.01**	0.16**	0.00**
Share of hhs using bio-pesticides	0.01**	0.05**	0.04	0.01**	0.03
Share of hhs intercropping with legumes	0.13	0.18**	0.03**	0.13	0.16**
Share of hhs practicing crop rotation	0.08**	0.14**	0.13	0.12	0.10*
Share of hhs using synthetic pesticides	0.06	0.08**	0.06	0.07	0.01**
Share of hhs using mineral fertilizers	0.01	0.07	0.07	0.1	0.08

Table 2.3 continued

	Type 1 n=65	Type 2 n=150	Type 3 n=106	Type 4 n=46	Type 5 n=121
Share of hhs that accessed credit in the last season	0.00**	0.03**	0.02	0.02	0.00**
Share of hhs that accessed credit in the last 2 years	0.00**	0.04**	0.02	0.02	0.00**
Share of hhs with accessed information on crop production	0.04**	0.11**	0.12*	0.05**	0.1
Share of hhs with accessed information on input use	0.01**	0.09**	0.06	0.01**	0.06
Share of hhs that have heard of organic agriculture	0.07**	0.16**	0.16*	0.10**	0.16
Share of hhs practicing certified organic agriculture	0.02**	0.04**	0.07	0.00**	0.12**
Share of hhs belonging to a social network (group, association)	0.02**	0.11**	0.1	0.05*	0.08
Average hh crop income per annum (p.a) in USD	99**	223*	222	186	244**
Average hh livestock income p.a	82**	207**	157	147	168
Average hh income from other agricultural employment p.a	18**	28	31	20	29
Average hh income from non-agricultural employment p.a	47**	117**	65	83	32**
Average hh business income p.a	37**	155**	85	90	30**
Average hh remittance income p.a	19	28	29	11**	29
Average hh pension income p.a	7**	55**	31	11**	24
Average hh income from other sources	15**	67	60	79	60
Crop gross margin	55**	310	321	349	374
Asset index	10.8**	23.9*	16.4	13.5*	12.5**
Dietary diversity index	31.7**	48.5**	42.8	33.5*	35.3**
Tropical livestock unit (TLU)	1.1**	2.1	3.4	5.8	1.7**
Gender index	71.0*	76.0*	73.4	71.2	77.1**

*Note: *represent significant levels of mean differences between the type under consideration and the other four types combined, significant at 5% (*p<0.05) and 1% (**p<0.01).*

2.4.1 Farm types

The following sub-sections (i.e. 3.1.1- 3.1.5) describe the characteristics of the five farm types in detail while Table 2.4 gives a summary of the same.

Type 1. Low resource endowment, mainly 'organic by default' and self-subsistence oriented (13% of the assessed farms)

This cluster comprised rather small farms with the lowest agricultural and non-agricultural incomes levels, the lowest levels of ownership of productive assets and livestock, and a high dependency on family labor (members worked off-farm the least). The cluster of Type 1 farms was also characterised by rather low adherence to many organic principles with the lowest levels of record keeping, mulching and cover cropping, use of biopesticides and crop rotation. However, they mainly used organic soil additions like manure, compost and recycled plant residue with most households adding some form of soil organic amendment while their use of synthetic pesticides was insignificant. These households had the lowest number of members compared to the other clusters, and middle-aged heads with the fewest years of education. They had not accessed credit in the previous season or the previous two years, and had the least access to information on crop production and inputs. In addition, they had the least knowledge of organic farming with a limited practice of certified organic farming, and the poorest social networks with the lowest levels of group membership. Finally, they had the lowest levels of dietary diversity and gender equity (Tables 2.3 and 2.4).

Type 2. High resource endowment, mixed conventional and organic market oriented (31% of the assessed farms)

The farm households of Type 2 were characterised by highest off-farm income levels from non-agricultural employment, business and pension, as well as the highest livestock and relatively high crop income. In addition to owning large pieces of land, they rented large shares of land and owned the most productive assets. Furthermore, these households adhered to many organic principles with the highest levels of practises such as mulching, cover cropping, use of biopesticides, crop rotation, intercropping, especially with legumes, and high use of organic soil additions with most household adding some form of soil amendment. However, they also had a high usage of synthetic pesticides. This implied that the cluster included a mixture of farms, some practising OA and the rest practising conventional agriculture. The cluster was also characterised by farm households with family members working mainly off-farm (least full-time work on-farm), and by the most educated and literate household heads. They also had the highest level of access to credit in the previous season and previous two years, and a high level of access to information on crop production and input use. They were strongly involved in social networks with the highest membership level in various groups, e.g. farmer cooperatives, church groups, and women and youth groups. Finally, these households had the highest levels of dietary diversity and gender equity (Tables 2.3 and 2.4).

Type 3. Medium resource endowment, mainly organic and market oriented households (22% of the assessed farms)

The cluster of Type 3 represented farm households that owned, rented and cultivated relatively small farms and, although not significant, the levels of both agricultural and non-agricultural income, gross crop margins and livestock ownership for these households were moderate. The household heads were highly literate. They adhered to many organic principles with the highest levels of record keeping, as well as high levels of mulching, cover cropping, and use of organic soil additions with most household adding some form of soil amendment. However, they mainly planted their crops in pure stands, and intercropped to a lesser extent with legumes. When intercropping, they did so in different parts of the farm. These households had the highest access to information on crop production and a high knowledge and practice of OA. Finally, although not significantly different from the other farm types, their dietary diversity and gender equity levels tended to be rather moderate (Tables 2.3 and 2.4).

Type 4. Predominantly low to medium resource endowment, conventional and market oriented, youngest heads (9% of the assessed farms)

The cluster of Type 4 comprised farms that relied mainly on rented land, most of which was cultivated. They had the lowest levels of income from remittances and pensions. This type also possessed moderate amounts of productive assets and, although not significantly different from other types, had high gross crop margins. These households showed the least adherence to organic principles with low levels of biopesticide usage, mulching, cover cropping and organic soil additions with many households not adding anything to soils at all. Although not significantly different from the other farming types, they had a relatively high usage of synthetic pesticides. In addition, the households had a low level of access to information on crop production and input use, maintained poor social networks with low group membership levels, and their dietary diversity level was moderate (Tables 2.3 and 2.4).

Type 5. Predominantly high to medium resource endowment, mainly certified organic and market oriented (25% of the assessed farms)

The farm households in the cluster of Type 5 owned and cultivated the largest farms and relied the least on rented land. They had the highest crop income but the lowest income from non-agricultural employment and business, and although not significantly different from the other types, their crop gross margins were the highest. However, their ownership of productive assets and livestock was low. These households adhered to many organic principles with high levels of record keeping, mulching and cover cropping, crop rotation, intercropping, especially with legumes, and high usage of organic soil additions with most household adding some form of soil amendment. They had the lowest levels of synthetic pesticide usage. In addition, the households were the largest with the oldest and least literate household heads. These farms strongly depended on family labor, and they had not accessed any credit during the previous season or the previous two years. However, they had the highest level of practice of OA and a high knowledge of it. Finally, this type had the highest level of gender equity and a moderate dietary diversity (Tables 2.3 and 2.4).

Table 2.4 Summary of main significant ($p<0.05$) characteristics of the different farm types.

Farm type	Name of farm type	Share	Household related	Resource endowment	Cropping practice	Social networks and information	Development outcome variables
1	Poorest, organic-by-default self-subsistence oriented	13%	-small -middle-aged heads -less educated heads	**low** -least land, assets and livestock owned -no credit access -lowest income -based on family labor	mainly 'organic by default'	-weakest social networks -least access to information	-poorest diets -most inequitable
2	Wealthiest, mixed and market oriented	31%	-most educated and literate heads	**high** -based on hired labor -ample off-farm activities -large size of rented land - highest credit access -highest income	mixed (both organic and conventional)	-strongest social networks -high access to information	-richest diets -equitable households
3	Moderately wealthy, organic and market oriented	22%	-highly literate heads	**medium** -smaller land sizes owned and rented	mainly organic -planting mainly pure stands	-strong social networks -highest access to information	

Table 2.4 continued

Farm type	Name of farm type	Share	Household related	Resource endowment	Cropping practice	Social networks and information	Development outcome variables
4	Poor, conventional and market oriented	9%	-youngest heads	**low to medium** -rely on rental land -moderate asset ownership -low remittance and pension income	conventional	-weakest social networks -poor access to information	-less diverse diets
5	Wealthy, organic certified and market oriented	25%	-oldest heads - least educated and literate heads -largest families	**high to medium** -largest farm sizes owned -no credit access -few assets and livestock owned -high farm income -limited off-farm activities	mostly organic certified		-moderately diverse diets -highly equitable

2.4.2 Distribution of farm types in Kajiado and Murang'a counties

Approximately one-third (31%) of all smallholder farms that were analysed belonged to Type 2, which was the wealthiest group. The same proportion of farms belonging to Type 1, which were the poorest farm households, was found in both counties and almost the same proportion of Type 3 farms was also found in both counties. The mainly conventional farm households of Type 4 were a minority, making up only 9% of the total number of households assessed, and were mainly found in Kajiado (15%) rather than in Murang'a (4%). Kajiado county was dominated by the wealthier farmers of Type 2 (41%), that were either practising conventional or organic farming. In contrast, Murang'a county was dominated by high to medium resource-endowed households that were mainly organic (Type 5) making up 39% of the farms of this type in the county (Table 2.5).

Table 2.5 Sample by farm type and county.

Overall sample (n=488)		Murang'a (n=246)		Kajiado (n=242)	
Type	Proportion (%) in survey	Number in type	Proportion (%) in Murang'a	Number in type	Proportion (%) in Kajiado
1 (n=65)	13	33	13	32	13
2 (n=150)	31	50	20	100	41
3 (n=106)	22	58	24	48	20
4 (n=46)	9	9	4	37	15
5 (n=121)	25	96	39	25	10

2.4.3 Drivers of variability among farm types and association among variables in relation to organic agriculture

Household-related variables

Farming types differed significantly ($p<0.05$) in terms of the age of the household heads, their education and literacy levels as well as the farm household size (Table 2.3). The findings reveal a negative correlation between age and education level of the household heads as well as their ability to read and write (Figure 2.1A). In particular, the heads of Type 5 households were the oldest and had the lowest education and literacy levels.

Farmers of Type 4, on the other hand, were the youngest, and although not significant, their education and literacy levels were relatively higher than for the other types (Table 2.3). Nevertheless, the age of the household head was positively correlated to the practice of certified OA as well as ownership and use of legally owned land (Figure 2.1A). This indicates that the practice of certified OA was not dependent on the level of formal education but rather on the age and experience of the household head.

In addition, a positive correlation was found between agricultural income from crops, livestock, agricultural employment as well as pension, and the use of land owned legally with the practice of certified OA. At the same time, a positive correlation existed between variables related to non-agricultural income such as that from business and non-agricultural employment with the use of rental land (Figure 2.1 A and C). Farms practicing certified OA under a certification scheme therefore seem to have higher incomes from these activities and have access to their own land while farmers not practicing OA or at least not under some certification scheme have to rent land and complement income from agriculture with a higher level of non-agricultural employment.

Resource endowment in relation to cropping practices and orientation

The size, ownership and cultivation of land, ownership of productive assets and livestock, as well as agricultural and non-agricultural income, labor and access to credit, were all discriminating factors for the different farm types (Table 2.3). Variables of agricultural income and legal land ownership and use were correlated with each other. The size and use of rented land and non-agricultural employment income were also correlated with each other. In addition, the practice of OA was positively correlated with size and use of legally owned land as well as age of the household head, while it was negatively correlated with the use of rented land and non-agricultural employment income (Figure 2.1 A and C). Type 2 and 5 farms, which consisted of certified organic farmers owned larger farm areas. Type 1 farms, which can be classified as organic-by-default, had the least access to legal or rented land, while the mainly conventional Type 4 also owned much smaller farms and relied more on rented land.

Access to credit was strongly correlated to income from business and other sources. Ownership of productive assets correlated to income, both agricultural and non-agricultural (Figure 2.1. A and C). Farm households that possessed high-income levels from diverse sources, e.g. Type 2, appeared to have a higher level of asset ownership than their counterparts in Type 1 (Table 2.3).

The variables full-time on-farm and off-farm labor differed significantly among the farm types. While Type 2 farms were mainly based on full-time off-farm family labor, implying a reliance on hired labor, Type 1 and 5 farms relied on full-time on-farm family labor (Table 2.3). As noted earlier, ownership of livestock was a weak discriminating factor between the farm types (Figure 2.1 A and C). Nonetheless, it differentiated farm household Types 1 (1.1 TLU) and 5 (1.7 TLU), who owned a relatively smaller number of livestock than the other farm types. In addition, Type 5 farms were larger than Type 1 farms, who relied mainly on rented land (Table 2.3). Access to credit was positively correlated to the education level and literacy of the household head (Figure 2.1 A). Farm households Types 1 and 5 characterised by low levels of education and literacy had not accessed any credit in the previous season or even in the previous two years. In contrast, Type 2 households had the highest literacy levels and the highest level of access to credit. Access to credit was, however, not strongly linked to the practice of certified OA (Figure 2.1A and Table 2.3).

Cropping practices

The way in which farm households managed their farms differed significantly between farm types and their levels of resource endowment (Table 2.3). There was a positive correlation between adherence to OA and management practices like record keeping and the use of organic soil additions according to the practice of certified OA. Farms of Type 3 had similar characteristics but differed from Types 2 and 5 first in their choice to either plant pure stands or both pure and intercropped stands but in separate parts of the farm, and second in their smaller farms sizes. However, farms of Type 2 had a significantly higher usage of synthetic pesticides compared to Type 5 where there was almost no usage of these at all. Both Types 1 and 4 showed a low adherence to OA principles (Table 2.3), which could be explained by their low levels of wealth.

The practice of certified OA was also strongly and positively correlated with income from agricultural sources especially from the sale of crop harvest indicating market orientation, but also non-agricultural income like pension as well as access to information and group membership (Figure 2.1 A and C). The association between the practice of certified OA and access to credit was relatively weaker (Figure 2.1 C). The correlation tables do not show a marked association between dietary diversity and gender equity for farm Types 1 and 4, which did not practice certified OA and had less diverse diets compared to the other farm types (Table 2.3).

Social networks and access to information in relation to organic agriculture

There was a strong positive correlation between group membership and access to information on crop production and input use. For instance, participation of farm households Type 1 and 4 in groups and their level of access to information on crop production and input use were low. In contrast, the opposite was true for households Type 2 and 3. Group membership was also positively correlated with agricultural income, knowledge and practice of OA and, to some extent, credit access. Interestingly, it appears that farm types with moderate to high levels of practice of OA had a high level of participation in groups, agricultural income and access to information compared to non-organic farming households (Figure 2.1 A and C; Table 2.3). These results indicate the importance of access to information for the dissemination of organic farming practices.

The knowledge and practice of OA was highest in Type 5 and lowest in Type 1. Results indicate that Type 4 farmers had the least knowledge of OA and did not practice it at all. Overall, results largely indicate a connection between the level of resource endowment of a farm household and the knowledge and practice of OA. The farm households that were highly to moderately resource endowed showed high adherence to many OA practices and had more knowledge and experience in practising it. This was in contrast to medium to low resource-endowed households (Table 2.3).

Dietary diversity and gender equity

Overall, the average score for gender equity in financial decision-making and control over resources as well as for sharing of household responsibilities was high in both counties (> 70%). However, dietary diversity was rather low with an average score of 40% (Table 2.1). Diversity in diets and gender equity in farm households were correlated with each other as well as variables of high resource endowment. Dietary diversity was strongly correlated to education level and literacy of the household (Figure 2.1 A and C). These variables did not have a strong association to the practice of certified OA, but they significantly ($p < 0.05$) distinguished farm households (Table 2.3). Farm households with the lowest levels of resource endowment (Type 1) had the lowest levels of dietary diversity and were the least equitable in terms of gender. Those with medium to high levels of resource endowment (Type 2 and 5) had equally high levels of dietary diversity and gender equity. Dietary diversity differentiated all types from each other apart from Type 3, while gender equity differentiated Type 1, 2 and 5 (Table 2.3).

2.5 Discussion

The results of this study show key differences across the five identified farm types. The distribution of the types in terms of the share of each type also varied between the two counties. In the following sections, the factors influencing diversity in smallholder farms and their implications are discussed in relation to the categories of variables that defined the typology, how they relate to each other and to the identified farm types. In addition, we link these categories to the study area and to the practice of OA.

Household characteristics

The farm household typology reveals the importance of the age, education and literacy level of the household head as well as the size of the household in explaining diversity in smallholder farms in the two case counties. Other studies reported similar findings albeit with variations. For instance, van de Steeg et al. (2010) found that family size and years of education explained heterogeneity in the five farm types they found in the

Kenyan highlands. Sakané et al. (2013) observed that household size was a significant discriminant of farm types in Kenya and Tanzania, but that age of the household head was not. In Rwanda, the significant household discriminants were family size, age as well as education and the literacy level of the household head (Bidogeza et al. 2009). The inverse link between age and education as well as literacy level of the household head was also reported by Bidogeza et al. (2009) in Rwanda, where young household heads were more educated. The education level of the household head has been argued to be important for household welfare. Marenya and Barrett (2007) suggested that it was a key determinant of the overall household well-being and productivity. The results of this study show this is true for farm Type 1 and 2, but not for Type 5. Similar findings were reported in Ethiopia where certified smallholder farms were headed by relatively older household heads with a mean age of 48 years who had a low level of education (Jena et al. 2012).

The relationship between resource endowment and the above household variables varied in different studies in SSA. For instance, farm types with a high level of resource endowment were linked to older household heads (Tittonell et al. 2010; van de Steeg et al. 2010) and large household sizes (van de Steeg et al. 2010; Sakané et al. 2013; Kuivanen et al. 2016a). In accordance with this, this study reveals that Type 5 farm households with the oldest household heads were the largest, while Type 1 farms that had middle-aged heads had the smallest household size. However, Signorelli (2016) found that wealthier households headed more by young households with high levels of education.

Generally, however, the results of this study suggest that farming in the sampled households is mainly practised by the older generation. This finding is similar to that of Mutoko et al. (2014) in western Kenya. Majority of the youth lack formal education beyond high school and have no vocational training or professional skills. Due to minimal employment opportunities in the rural areas, they tend to migrate to urban areas where they mainly provide informal labor (Njenga et al. 2011; ILO 2016).

The low level of youth involvement in agriculture in Kenya has been attributed to the poor transitional pathway from education in agriculture to work in the same, the youth access to land, and a negative perception of farming among the youth, who associate it with long working hours and limited returns. Radwan (1995) argued that employment-intensive growth is a vital strategy for poverty reduction. For agricultural growth aimed at reducing poverty, it is therefore necessary to distinguish the important role of household factors. First, support for youth education beyond high school, and greater emphasis on vocational training can provide these young people with the tools to engage competitively in the formal sector. Investing in human capital through education and training has been argued to help increase productivity and earnings of the poor, as farmers can absorb new ideas and innovations with much more ease and can respond to market opportunities, among other benefits (Radwan 1995).

Secondly, the older generation that is engaged in farming cannot be ignored. The results of this study indicate that the level of wealth of the oldest, least educated and least literate group with the highest level of practice of certified OA (Type 5) could have been higher had they been able to access credit, which in addition to the reasons given above for low credit access, was also influenced by their education and literacy levels. Basic training, for example in book keeping, financial administration, marketing as well as in technical skills, could benefit them. Moreover, they also seemed to have large families, and other family members, especially the young and their farm workers who are mostly young too, could benefit from formal trainings to support/replace the old household heads. For farm household heads of Type 1, who were relatively younger and literate but with lower education levels, education aimed at enhancing their technical skills would enable them to adopt new technologies

Resource endowment and farming practices in relation to organic agriculture

A third of the farms sampled belonged to Type 2 and were well endowed. These farms had diversified livelihood strategies with abundant off/non-farm activities and income, relied on hired labor, had high access to external financial capital and rented land to supplement their own. In contrast, resource-constrained farms belonging to Type 1 who depended on on-farm labor or off-farm employment as casual laborers had self-subsistence orientation. These two types correspond to other typologies for smallholder farmers in Kenya (Shepherd and Soule 1998; Tittonell et al. 2005; Mutoko et al. 2014), Uganda (Tittonell et al. 2010), and West Africa (Signorelli 2016; Kuivanen et al. 2016a). Type 5 farms differed from the other types, as their strategy did not include diversification. Despite being relatively well endowed, they were heavily reliant on farm income mainly from crops and had no access to external financing, which could explain their limited ownership of productive assets as well as livestock. This farm type was similar to a type found in Ghana by Kuivanen et al. (2016a).

In a comparison of several other studies in SSA, a positive association was reported between income diversification and wealth (Barrett et al. 2001a). Although dependence on on-farm activities is still common in rural Africa, Davis et al. (2017) found that a greater reliance on non-farm sources of income was linked to households being richer in six SSA countries. However, C. B. Barrett et al. (2001) acknowledged the vicious cycle between the unequal distribution of land and non-farm income, where limited agricultural assets and income hinder investment in non-farm activities. For instance, low credit access has been reported among smallholder farmers in Kenya due to high capital requirements for loan collateral, as lenders try to cushion against non-repayment or delay in loan repayment, poor information access on credit providers, and lack of interest payments (Mutoko et al. 2014; Ayuya et al. 2015).

Land entitlement deeds can be used as loan collateral (Place 2009). For the farms of Type 1, resource constraint may explain the lack of credit access. Nonetheless, farmers may still not access formal credit even if they have title deeds as evidenced by Type 5 farms, most of which are located in Murang'a, where a general reluctance to obtain formal credit has been reported (MCDP 2013). This has been attributed to perceived unfavourable terms such as high interest rates, dispossession of land (normally due to failure to pay back loans), and land fragmentation (Ekbom et al. 2001). Despite Kenya's relatively well-developed banking sector, agribusiness is viewed by banks as highly risky, and complex tenure systems and land laws have been argued to accentuate the problem for smallholder farmers (Njenga et al. 2011).

For the poorest farms (Type 1) who are most vulnerable to risks, interventions could first focus on alleviating poverty and food insecurity. Literature suggests that this can be done through measures aimed at increasing their productivity, which depends on many factors such as farm size and access to land as well as on new technologies and their adoption (Radwan 1995; Dethier and Effenberger 2012; Kuivanen et al. 2016a). Since these farmers already own or have access to small farms, other measures like promotion of high yielding crop varieties, reduction of post-harvest losses by improving storage facilities, and assistance in access to inputs could address the immediate need of poverty and food insecurity (Kuivanen et al. 2016a). For Type 5 farms, diversification in off/non-farm activities would also generate income (Barrett et al. 2001a; Kuivanen et al. 2016a), which could be invested in the purchase of more productive assets. In addition, given the large size of farm households in Type 5, technologies that require relatively more labor but are at the same time efficient (Kuivanen et al. 2016a) could be promoted. Development interventions could support the younger farmers in Type 4 in accessing productive assets including land and capital to boost productivity (Radwan 1995).

Social networks and access to credit and information

This study reveals a strong positive link between variables of access to information and group membership as well as their association with wealth. Other studies in Kenya and Uganda showed that strong social networks positively influenced information acquisition (Thuo et al. 2014), and also income diversification in India (Davis et al. 2017). High resource endowment was linked with a greater likelihood of group membership for smallholder banana farmers in Kenya (Fischer and Qaim 2012). The authors also found that these banana farmer groups were avenues of information exchange, and wealthier farmers could overcome some constraints like membership fees.

In addition, information acquisition and utilisation are influenced by literacy, affordability, linkages with external support to farmers (e.g. from extension officers) as well geographical location (Maumbe 2010; Thuo et al. 2014). Technical information, e.g. on input use, pest and disease management and sources of various inputs, is a major information gap among farmers in Kenya. Poor extension services, long distances to agricultural service providers, especially in the ASAL regions, and weak institutional linkages have been argued to be major impediments to information access among these farmers (Rees et al. 2000a; Omondi et al. 2014). Despite these challenges, the information and communications technology sector is well developed in Kenya. For instance, the mobile telephone technology is widely used by farmers not only for communication purposes but also for services like mobile banking. This is an opportunity to provide information to farmers, and could also enable transfer of social grants to poor farmers (Maumbe 2010)

Dietary diversity and gender equity

The results of this study also show a positive link between dietary diversity (i.e. proxy food security), gender equity and levels of resource endowment as well education and literacy levels of household heads, and their relevance in distinguishing farm types. These findings are comparable to those in other studies. In western Kenya, wealthier households with better educated women were found to have higher dietary diversity (Ng'endo et al. 2016). In the same region, Tittonell et al. (2010) found a link between food sufficiency, a proxy for food security, and the land:labor ratio (LLR), an indicator of wealth as well as market orientation. The authors found that all households that were food insecure had a lower LLR in contrast to those identified as food secure. In Uganda, high income was associated with improved gender equity as well as improved diets (Chiputwa and Matin 2016). In Ghana, Signorelli (2016) found that low-endowed households, which were mainly female-headed, had high rates of food insecurity and low literacy rates, while the opposite was true for the wealthy farm households.

The diversity of diets has been argued to be an important indicator of micronutrient adequacy, which is associated with food and nutrition security (Alvarez et al. 2014). Given these linkages, addressing challenges of food insecurity and inequality found for farm Type 1 and 4 could start with improving education levels of women and wealth as well as its distribution. For instance, the measures mentioned above aimed at reducing pre- and post-harvest losses as well as improving education especially of women who prepare the food, would help to increase dietary diversity as well as gender equity. Social protection for the poorest and most food-insecure groups through targeted cash or input transfers can address the problems only in the short term. In the long run, value-chain issues like improved market linkages and access to resources, especially land and capital, could be addressed.

Organic agriculture in relation to farm types

The adherence to practices associated with OA was high among older and wealthier farm households, but not necessarily the more educated farm household heads. Jena et al. (2012) had a similar finding, which they attributed to the ability of older farmers to earn more because they were more knowledgeable and established than younger farmers. With regard to cropping practices, Type 3 farms planting mainly pure stands could be encouraged to introduce intercropping especially with legumes given the multiple benefits associated with the practice (Mucheru-Muna et al. 2010). The mixed farms in Type 2 farms that are already quite productive and economically well-endowed, as well as Type 4 farms, may need support to manage their soil due to their high usage of agrochemicals (Kuivanen et al. 2016a). Land-tenure security, which represents rights to hold, use and transact land (Adams 2001), was of particular importance for the practice of certified OA in this study. Organic agriculture is associated with long-term investment in soil conservation measures, which is strongly linked to secure land tenure (Gebremedhin and Scott 2003). The negative effects of insecure land tenure on soil conservation investments is widely known from the literature (Shepherd and Soule 1998; Fraser 2004; Place 2009).

In Kenya, land tenure can be communal based on traditional ownership with rights to use but not to sell, private with title deeds under freehold, leasehold or government trust land (GoK 2009). Land rights are overall quite secure in Murang'a, being based on a system of inheritance whereby parents subdivide their land between their children with allocation of title deeds (Mackenzie 1989; Ekbom et al. 2001). Kajiado county has been evolving from a communal system of ownership to freehold (Campbell et al. 2000; Ogutu et al. 2014). Privatisation of land rights is linked to increased tenure security, which in turn provides collateral for formal credit and increases the incentive to invest in more land or inputs, which ultimately may increase productivity (Place 2009).

However, challenges to land tenure such as uncertainties regarding land rights, unequal distribution of land, and poor mechanisms for the transfer of land rights contribute to poverty and food insecurity (Radwan 1995; Salami et al. 2010). Radwan (1995) argued that access to land and physical assets can contribute to poverty reduction in SSA. Therefore, the land reform that is already ongoing in Kenya needs to facilitate the access to land as well as tenure security to farmers, the youth and other vulnerable groups (WFP 2016) especially in the ASAL regions of the country.

The practice of certified OA was also associated with greater access to information, strong social networks, equitable family structures and more diverse diets as well as older household heads. However, this study did not determine causal relationships between the practice of certified OA and these variables. Nonetheless, Chiputwa and Matin (2016) found that organic certification of smallholder organic coffee farmers in Uganda led to improved diets in terms of calorie intake and dietary diversity, mostly due to higher incomes and improved gender equity. They found that organic certification enhanced women empowerment through special training, awareness creation and gender mainstreaming activities encompassed in the process. Since the organic farmers in our study belonged to farm households with medium to high resource endowment, similar reasons of higher economic access enhancing dietary diversity and gender equity could apply.

Organic certification is also associated with several benefits such as access to high-value markets, increased access to credit, increased social capital through extensive training, and increased profitability and it has been reported to reduce poverty (Barrett et al. 2001b; Bolwig et al. 2009; Jena et al. 2012; Ndungu et al. 2013; Ayuya et al. 2015). However, given the high cost of certification, Barret et al. (2001) argued that smallholder farmers forming groups, obtaining external funding, participating in contract schemes and in some cases seeking national rather than international certification, could help overcome this challenge. For policy makers, direct subsidies on organic inputs similar to those given for mineral fertilizer in Kenya could encourage especially poor farmers to practice OA. In Finland for instance, it was reported that converting to OA was triggered by subsidies especially for farms that had large land areas and low yields (Pietola and Lansink 2001). Given the importance of social networks for farmer information access, smallholder farmers and the youth, even if these are not involved in farming, could benefit from becoming involved in existing groups or from forming new ones.

This study also reveals differences between the two counties in terms of how the five farm types were distributed. Kajiado was dominated by mixed conventional and organic high-resource endowed farms with quite diversified livelihood strategies (Type 2), while Murang’a was mainly dominated by certified organic farms whose livelihoods seemed to be reliant on agriculture (Type 5). Farms of Type 1 and Type 3 were equally abundant in both counties, while farms with the youngest household heads (Type 4) were mainly located in Kajiado. It was beyond the scope of this study to prove if this varying distribution of farm types is because of climatic heterogeneity. However, from the findings it is reasonable to assume that the overall greater reliance on agricultural activities and income in Murang’a is due to its higher bio-physical agricultural potential. Kajiado on the other hand, being an ASAL region, is prone to erratic weather conditions including recurrent drought and floods (Campbell 1984), and with a need for irrigation to supplement rainfall for crop cultivation. Hence, diversified livelihoods would cushion farmers against these environmental shocks.

Limitations of the study

Because of time and financial resource constraints, this study was subject to a number of limitations. A participatory approach, as recommended by Kuivanen et al. (2016b), was thus not possible. However, various informal meetings with farmers and other local stakeholders were conducted in both counties and in Nairobi. The sample size of the study also had to be limited to approximately 500 farms. In addition, the study did not capture the spatial distribution of biophysical factors, which could have helped to explain the distribution of the farm types as well as the adoption of organic farming practices based on geographical and environmental conditions. However, we decided to classify farms mainly from a socio-economic point of view and tried to include a diversity of environmental conditions through the selection of two biophysically different counties. Although typologies are useful to understand the diversity of smallholder farm households, they are limited in their ability to accurately capture every aspect of dissimilarity. In addition, this categorisation is based on a one-time measurement giving a snapshot of the situation on the farms at the time the study was conducted. However, smallholder farms are dynamic and production systems can rapidly change, hence farm typologies need to be constantly updated (Alvarez et al. 2014). Nevertheless, this study endorses findings by previous farm typology studies carried out in Kenya, as well as in other countries in SSA, where similar patterns were observed. This was a cross-sectional study and its results should be interpreted with caution as it did not determine causal relationships between the variables. Finally, despite its attempts to capture climate heterogeneity, this study falls short in representing the whole diversity of Kenya's biophysical conditions.

2.6 Conclusions

In this study, smallholder farms in Kajiado and Murang'a counties in Kenya were characterised and classified into five distinct types. The characteristics of the farms were analysed with a focus on aspects influencing the transformation of farms to OA in the country. With regards to the first research question, a typology was found with significant differences among five farm types. The distinguishing characteristics were based on resource endowment, household-related factors, cropping practices, production orientation, social networks, information access, dietary diversity and gender equity. Wealthier smallholder farms practising both organic and non-organic (conventional or organic-by-default) agriculture dominated Kajiado while Murang'a was dominated by farms practising OA with medium to high wealth levels. Concerning the second question, farmers practising certified OA were wealthier but not necessarily better educated than those who did not, which was attributed to higher experience and greater access to productive resources unlike their younger counterparts. The practice of OA (certified and uncertified) was more likely to be found in smallholder farms that had legal land tenure rights, moderate to high income levels, especially from agricultural sources, with older household heads that were well informed with strong social networks, a large number of household members, and equitable family structures and highly diverse diets. However, this study did not determine causal relationships between these factors and the practice of OA.

The characteristics of typical farm households found in an area and identified through typology construction can form a basis for understanding current practices as well as for targeting future interventions. Programs aiming to address agricultural growth in Kajiado and Murang'a as well as in similar regions in Kenya need to take into consideration the challenges and opportunities associated with the farm types identified in this study, which are similar in many aspects to others identified by farm typology studies in the region. The significant role of resource endowment in reinforcing the cycle of imbalance through a system that benefits wealthier over poorer, older over younger or men over women farmers, suggests the need to address this inequality in order to reduce their vulnerability to different shocks and aid in wealth accumulation which will enhance their spending power. Empowering women has been shown to translate to better diets for the household and increase their control of resources and decision-making capacity.

Based on this typology, effective pro-poor development strategies seeking to improve productivity and welfare of smallholder farms and farmers respectively should be systematically targeted. For instance, resource constrained farms in Type 1 and 4 could benefit from interventions that target access to capital particularly land, low-input technologies, high yielding and biofortified crop varieties. They could benefit from participation social networks in their communities, especially where no barriers of entry like membership fees exist, as these networks have been shown to be ideal places for information sharing. Type 5 farms could benefit from efforts towards income diversification into non- and off-farm activities, increased credit access as well as improving their literacy levels. The wealthier conventional farms in Type 2 could be encouraged to use more improved technologies, inputs and farming practices that are environmentally friendly including certified OA, and since both Type 2 and 3 are highly literate, they could benefit from more knowledge intensive technologies. Finally, Type 3 farms could be encouraged to adopt more intercropping, and assisted to gain greater access to productive resources.

Given the growing local and international markets of organic produce and the benefits associated with OA, as well as policy interest in these sector, efforts aiming promote certified OA in the study area and other parts of Kenya should also seek targeted and problem oriented strategies. For certifiers, purchasers and traders of certified products and development stakeholders, this may include local or other cost-effective certification strategy such as group certification in contract schemes or PGS systems to overcome barriers of entry to the organic market, particularly for farmers already practicing uncertified OA like some in Type 2 and 3. Increase in knowledge about OA and its benefits could also encourage farmers to adopt this practice. However, further research, particularly in studies with larger samples; including spatial distribution factors, in-depth participatory techniques and qualitative methods is needed.

3 HOLISTIC SUSTAINABILITY ASSESSMENT OF SMALLHOLDER FARMS IN KENYA

3.1 Abstract

Sustainable development in sub-Sahara Africa (SSA) is closely linked to the sustainability of smallholder farming. The growth of organic agriculture among smallholders in Kenya raises the issue of its sustainability performance in the context of highly heterogeneous smallholder farms and varying agro-ecological conditions in the country. The aim of this study was to assess the sustainability performance of organic and non-organic farms in two biophysically different regions in Kenya, i.e. the counties Kajiado and Murang'a, using the SMART-Farm Tool, which is based on the SAFA Guidelines of the FAO that define four sustainability dimensions: Good Governance, Environmental Integrity, Economic Resilience and Social Well-Being. The study distinguishes between two certification statuses, i.e. between certified and non-certified (mixed farms), and between the two counties and five different farm types characterized based on differences in farming practices, farm and household characteristics, market orientation, household size, etc. Household survey data was collected from 400 smallholder farms purposively sampled. Multivariate analysis of variance (MANOVA), multiple general linear models and posthoc tests were used sequentially to determine if the five farm types, the two certification statuses, and two counties differed in their sustainability performance. Irrespective of farm type, certification status and county, results indicate that all farms lack reliable management information, and that only limited knowledge, skills and social security exist for farmers and farm workers.

There were no major differences in sustainability performance across the five farm types, but organic certified and non-certified farms differed considerably, with certified farms performing more sustainably due to better training and social security, higher economic resilience as well as higher water quality and biodiversity. However, there were no major differences between certified and non-certified farms in terms of profitability, animal husbandry practices, water use or cropping practices except that certified farms did not use synthetic chemical pesticides or seed dressing and incorporated more trees on their farmland. This indicates that many farms are applying

similar farming practices irrespective of being organic certified or not. Farms in Murang'a performed more sustainably than those in Kajiado except for the dimension of Environmental Integrity. Since differences in sustainability performance are based on the certification status of farms and on regional differences, a more detailed impact assessment targeting these factors to evaluate their impact is recommended. The results, however, identify those factors that are relevant to improve sustainability in smallholder farms, and can serve as a basis for policy and decision makers to identify appropriate interventions including relevant certification guidelines.

3.2 Introduction

Agriculture, mainly practiced by rural smallholder farmers, is still the mainstay of most people in sub-Saharan Africa (SSA), and the main driver of socioeconomic development (Altieri 2009; Salami et al. 2010; Davis et al. 2017). Consequently, sustainable agriculture has been identified as a crucial element for promoting sustainable development in SSA (Grenz et al. 2009; Conceição et al. 2016; Ozturk 2017). In addition to being the primary food producers, smallholder farmers are the core managers of natural resources (Tilman et al. 2002). Therefore, their role is crucial in addressing natural resource depletion and degradation, in decreasing agricultural productivity, food insecurity, poverty and for adapting to population growth, climate change, urbanization and land fragmentation (De Jager et al. 2001; Giller et al. 2009).

Kenya is exemplary for the importance of smallholder farming and its impact on land and society. The agricultural sector contributes approximately 25% of the gross domestic product and employs over 70% of the total labor force of the country (GoK 2009). Kenyan smallholder farmers (cultivating up to 3 ha) produce more than 65% of all agricultural output (GoK 2009; Njeru and Gichimu 2014). However, an estimated 50% of all Kenyans live in poverty, often with high levels of food insecurity, and the majority live in rural areas and practice smallholder farming (Krishna et al. 2004; ILO 2016; WFP 2016).

In the attempt to achieve the United Nations Sustainable Development Goals (SDGs) (UN General Assembly 2014), smallholder farmers are expected to play an important role through their agricultural and land-use practices (Grenz et al. 2009; Conceição et al. 2016; Ozturk 2017) in efforts to alleviate poverty and food insecurity (Altieri 2009). However, smallholder farmers in Kenya face multiple challenges such as decreasing soil fertility due to land degradation, which is exacerbated by poor farming practices that lead to soil nutrient mining (Mulinge et al. 2016) and to large yield gaps for almost all crops (Tittonell and Giller 2013). The farmers also have limited access to productive assets such as financial capital, markets, land, and inputs, and face high pre- and post-harvest losses (Altieri 2002; GoK 2009; Salami et al. 2010; Jouzi et al. 2017). Given their present circumstances, the sustainability of these farmers is uncertain especially in the face of demographic, climate and other changes (Godfray et al. 2010; Cohn et al. 2017). Therefore, a better understanding of smallholder farming could support decision makers in recognizing and undertaking suitable actions towards sustainable development.

Furthermore, smallholder farms in Kenya, like in other SSA countries, are highly heterogeneous and differ in many structural and functional aspects such as production goals, orientation and available assets, hence efforts aimed at addressing the challenges they face need to account for this diversity (Tittonell et al. 2005; Kuivanen et al. 2016a). Moreover, the highly varied biophysical conditions in Kenya also need to be accounted for to assess farm sustainability potential.

3.2.1 Organic Agriculture in sub-Saharan Africa

In an attempt to counter the challenges of smallholder agriculture in SSA, policy makers have focused on the promotion of more sustainable farming practices. Organic agriculture (OA), pushed forward by the “Ecological Organic Agriculture” (EOA) initiative of the African Union (AU), is one such approach. Policy makers and donors have recognized the potential of OA as a means of improving the livelihoods of smallholder farmers by producing agricultural products more sustainably and sustaining the natural resource basis (Bett and Freyer 2007; Niggli et al. 2016). Driven by a growing demand for organic produce in East Africa (Ayuya et al. 2015; Ndukhu et al. 2016) and the Global North, and supported by numerous international, state and non-state actors, OA is a booming trend (Niggli et al. 2016; Willer and Lernoud 2017). Organic smallholder farming in Kenya and other SSA countries comprise non-certified farmers and certified farmers using international or national certification schemes. Non-organic farmers include farmers using synthetic agrochemicals and low input-output systems with no use of agrochemicals at all, often described as 'organic by default'(Bolwig et al. 2009; Bennett and Franzel 2013; Ayuya et al. 2015).

Organic and other agricultural certification schemes usually attempt to increase environmental and social sustainability (González and Nigh 2005; Raynolds et al. 2007) by following specific regulations such as those prohibiting the use of chemically treated planting material, genetically modified organisms (GMOs), synthetic fertilizers and pesticides as well as non-organically produced feed and prophylactic use of antibiotics for livestock. These regulations also burden farmers with extensive documentation requirements, including comprehensive records of farm inputs and yields, and require a transition period of 2-3 years for reducing the level of soil contamination from input use, regular farm inspections and other requirements for the transport, processing and labelling of organic produce (Raynolds 2000, 2004).

The sustainability of OA is, however, contested. For instance, OA is criticized for generating lower yields, and that its inability to supply adequate amounts of nitrogen could translate into lower profitability and inadequate food production compared to conventional agriculture. However, on the other hand it has been credited for its potential to increase biodiversity, and to improve soil and water quality among other benefits (Seufert and Ramankutty 2017; Muller et al. 2017). In SSA, organic certification has been linked to improved profitability, increased social capital, poverty reduction and improved standards of living (Barrett et al. 2001b; Bolwig et al. 2009; Ndungu et al. 2013; Ayuya et al. 2015). However, it is undermined by high costs of certification, the not always guaranteed applicability of international regulations, and inadequate governance capacities (Barrett et al. 2002). Additionally, organic farmers in SSA face challenges similar to those of organic producers elsewhere including frequent changes in organic regulations, complex documentation procedures, bureaucracy in the certification process, as well as other economic, production and macro challenges associated with OA (Sahm et al. 2013). Due to the divergent views on the sustainability of OA in science and practice, better insight into the potential of OA, both certified and non-certified, compared to non-organic agricultural practices in contributing to sustainable development in SSA is needed.

3.2.2 Agricultural approaches to sustainable development: sustainability assessments and tools

Despite the potential of sustainability indicators to provide valuable information and a data basis to monitor and evaluate sustainable development (de Olde et al. 2016a), selection of such indicators strongly depends on the applied definition of sustainability (Rigby et al. 2001; de Olde et al. 2017). Schader et al. (2014) observed that the term sustainability was frequently used in cases where only the environmental dimension was covered by indicators or where similar indicators were used for the economic and social dimensions despite the fact that economic sustainability does not necessarily imply social sustainability and vice versa. In addition, indicator sets vary between different studies depending on scope (geographic area, thematic scope, dimensions), assessment level (product, farm, agricultural sectors), precision, assessment methodology including weights assigned, and the context (Dantsis et al. 2010; Schader et al. 2014b; de Olde et al. 2016a, c). Under these circumstances, finding a concise definition of sustainability and a universal approach to assess sustainability is difficult if not impossible (Pretty, 1995), and highlights the importance of transparency in the use of sustainability assessment tools (Schaller 1993; Sachs et al. 2010; de Olde et al. 2017). The choice of any sustainability assessment approach and specific tools has to be guided by the purpose (e.g. research, policy advice, extension), the scope, and the specific problem targeted (Schader et al. 2014b).

Sachs et al. (2010) proposed a systematic collection of sustainability data using similar criteria across sites and ecological zones to allow comparisons at similar scales. To select indicators for assessing sustainability, several frameworks have been developed and used as a basis. In agricultural systems for example, the guidelines for Sustainability Assessment of Food and Agriculture Systems (SAFA Guidelines) by the

Food and Agriculture Organization of the United Nations (FAO 2014) and the Sustainability Assessment of Farming and the Environment Framework (Van Cauwenbergh et al. 2007) have been used. In addition, several tools and approaches have been used to assess sustainability such as the Life Cycle Sustainability Assessment (LSCA), which is evolving from the traditional environmental and product-oriented LCA approach to a more holistic and transdisciplinary tool (Guinée et al. 2011). Others include the Response-Inducing Sustainability Evaluation (RISE), which is a farm advisory tool used for extension and less for research purposes, while the approach of the Committee on Sustainability Assessment (COSA) is a farm-level impact assessment tool. Both RISE and COSA fail to capture the whole supply chain like LCA, despite covering all dimensions of sustainability (Schader et al., 2014). More tools for sustainability assessment are well documented in literature and their number is rising (Schader et al. 2014b; de Olde et al. 2017).

Researchers have assessed the sustainability of smallholder farmers in Kenya based on various aspects, (sub-) themes and indicators. For instance, De Jager et al. (2001) focused on environmental and economic aspects of sustainability to compare low external input or organic management systems with those of conventional smallholders in Machakos County, eastern Kenya, using the nutrient monitoring approach. Onduru and Du Preez (2008) assessed smallholder farms based on three dimensions of sustainability in Embu County, also in eastern Kenya. Grenz et al. (2009) used RISE to assess environmental, economic and social sustainability of farms in a relatively humid area in Laikipia County, central Kenya, while Nzila et al. (2012) assessed the sustainability of biogas production in Kenya focusing on technical, economic and environmental aspects of sustainability by combining several criteria including LCA, energy and cost accounting. Other studies assessed different sustainability dimensions in smallholder farms in Kenya (Shepherd and Soule 1998; Mwirigi et al. 2009; Spaling et al. 2011).

Despite several studies on the sustainability of smallholder farming in Kenya, differences in definitions of sustainability, dimensions and indicators limit the comparability of their results and conclusions. Hence, this study intends to close this gap by adopting the SAFA Guidelines of the FAO, which is a comprehensive approach to produce nationally and internationally comparable and transparent results along food and agricultural value chains (FAO 2014). Unlike the standard definition of sustainable development of the Brundtland Commission that identifies economic, environmental and social dimensions (WCED 1987), SAFA Guidelines add the fourth and overarching dimension of 'Good Governance' for sustainability assessment that relates to the other three (Schader et al. 2016). Although there is no one size fits all framework or approach for sustainability assessment, the indicators based on the SAFA Guidelines possess scientific rigor and cover the major dimensions of sustainability (de Olde et al. 2016b).

In addition, to the best of the authors' knowledge, no published study has assessed sustainability of organic and non-organic smallholder farms in Kenya while taking into account both heterogeneity of farms and biophysical differences (e.g. climate and soils). Therefore, this study also contributes to the current state of knowledge by considering these factors as recommended in the assessment of agricultural sustainability (Chopin et al. 2017). In this regard, smallholder farms from two biophysically different counties (one humid to semi-humid and one arid to semi-arid) in Kenya were selected. A previously developed typology (Kamau et al. 2018) was used as another relevant level of analysis to control for other confounding variables and the general heterogeneity among smallholder farmers.

Many authors have argued that smallholder farmers are part of the solution in achieving sustainable development in SSA (Salami et al. 2010; Conceição et al. 2016). However, their contribution is challenged by complex socio-economic, ecological and demographic settings under which they operate. For example, the greatest population growth in this century will be in SSA, exacerbating the existing competition for natural resources (Gerland et al., 2014). Negative impacts of climate change pose other multiple serious challenges such as considerable yield reduction in key crops grown in SSA if sufficient adaptation measures are not taken (Schlenker and Lobell 2010). Assessing the sustainability of smallholder farms, that form the backbone of rural economies in SSA, can reveal barriers and opportunities for sustainable development and improve decision making by various stakeholders in and outside the agricultural sector, including the farmers themselves. This in turn can contribute to efforts aiming to alleviate poverty, reduce food insecurity and curtail natural resource degradation.

Against this backdrop, our study was designed to answer the following research questions: 1) What are the characteristic patterns and features of sustainability performance of Kenyan smallholder farms? 2) Do differences exist between the sustainability performance of smallholder farms practicing organic (certified or non-certified) compared to non-organic (i.e. conventional or low input organic-by-default) farm management? 3) Do differences exist in sustainability performance between the two biophysically distinct Kenyan counties?

3.3 Material and methods

3.3.1 General approach to farm and study area selection

In this study, we built on the diversity in smallholder farms reflected in a typology of smallholder farms that we developed in a previous study (Kamau et al., 2018). For this study, more or less the same proportion of certified organic farms (n=120) to non-certified farms (n=280) applied in Chapter 2 was involved. Out of the 400 smallholder farms sampled, 211 were in Murang'a, with about 38% certified organic compared to 189 in Kajiado, where about 21% were certified organic farms.

3.3.2 SAFA Guidelines and SMART-Farm Tool

In this study, we investigated the aspect of sustainability performance based on the SAFA Guidelines that considers four sustainability dimensions: Good Governance, Environmental Integrity, Economic Resilience and Social Well-Being. These four dimensions consist of a total of 21 themes and 58 subthemes (Figure 3.1). Each subtheme has defined objectives for assessing the sustainability of operators in the food and agriculture value chain (FAO 2014) (Figure 3.1 and Appendix B1).

We used the Sustainability Monitoring and Assessment RouTine (SMART)-Farm Tool, which operationalizes the SAFA Guidelines, following the same defined hierarchical structure of sustainability dimensions, themes and subthemes. The tool uses an impact matrix of 327 indicators to compute the degree of sustainability achievement, and measures the degree of goal achievement for each sustainability subtheme described in the SAFA Guidelines on the basis of multi-criteria assessments. Results are normalized to percentage scores on a scale of 0% to 100% indicating worst and best performance, respectively. A relevance check is integrated into the tool to enable automatic selection of relevant indicators for standardizing the questionnaire and thus ensuring comparability between different regions, farm types and farming systems. Each indicator has a weight on a certain subtheme. These weights are expressed on a scale of -100% to 100% indicating the size of the negative or positive impact of a specified indicator on a subtheme. The impacts of each indicator in relation to a subtheme were predefined and experts estimated their magnitude/weight. To integrate the performance on the various indicators, the results of the indicators are aggregated to the subtheme level using a weighted sum algorithm. The sum of the performance rating of respective indicators in relation to the sum of impact weights of respective indicators provides the sustainability score at the subtheme level, and is termed as degree of goal achievement (Eq. 1, details in Schader et al., 2016).

$$DGA_{ix} = \sum_{n=1}^{N} (IM_{ni} \times IS_{nx}) / \sum_{n=1}^{N} (IM_{ni} \times ISmax_n) \;\forall\; i\ and\ x \quad \text{(Eq.1)}$$

where DGA_{ix} is degree of goal achievement of a farm *x* with respect to a subtheme *i*; IM_{ni} is the impact weight of indicators *n* (*n*=1 to N) that are relevant to the sub-theme *i*; IS_{nx} is the performance of a farm *x* with respect to an indicator *n*; $ISmax_n$ is the maximum possible performance of an indicator *n*. The tool generates sustainability reports for each farm (Schader et al. 2016).

To determine the performance of each farm in relation to each relevant indicator and with respect to a given subtheme, the RI_i value was calculated according to Eq. 2:

$$RI_i = (IM_{ni} \times IS_{nx}) \;\forall\; i\ and\ x \quad \text{(Eq. 2)}$$

where RI_i is impact rating representing the product of IM_{ni} and IS_{nx}. The *RI* value helped to understand which indicators contributed to poor performance or to large differences in the performance of the subthemes.

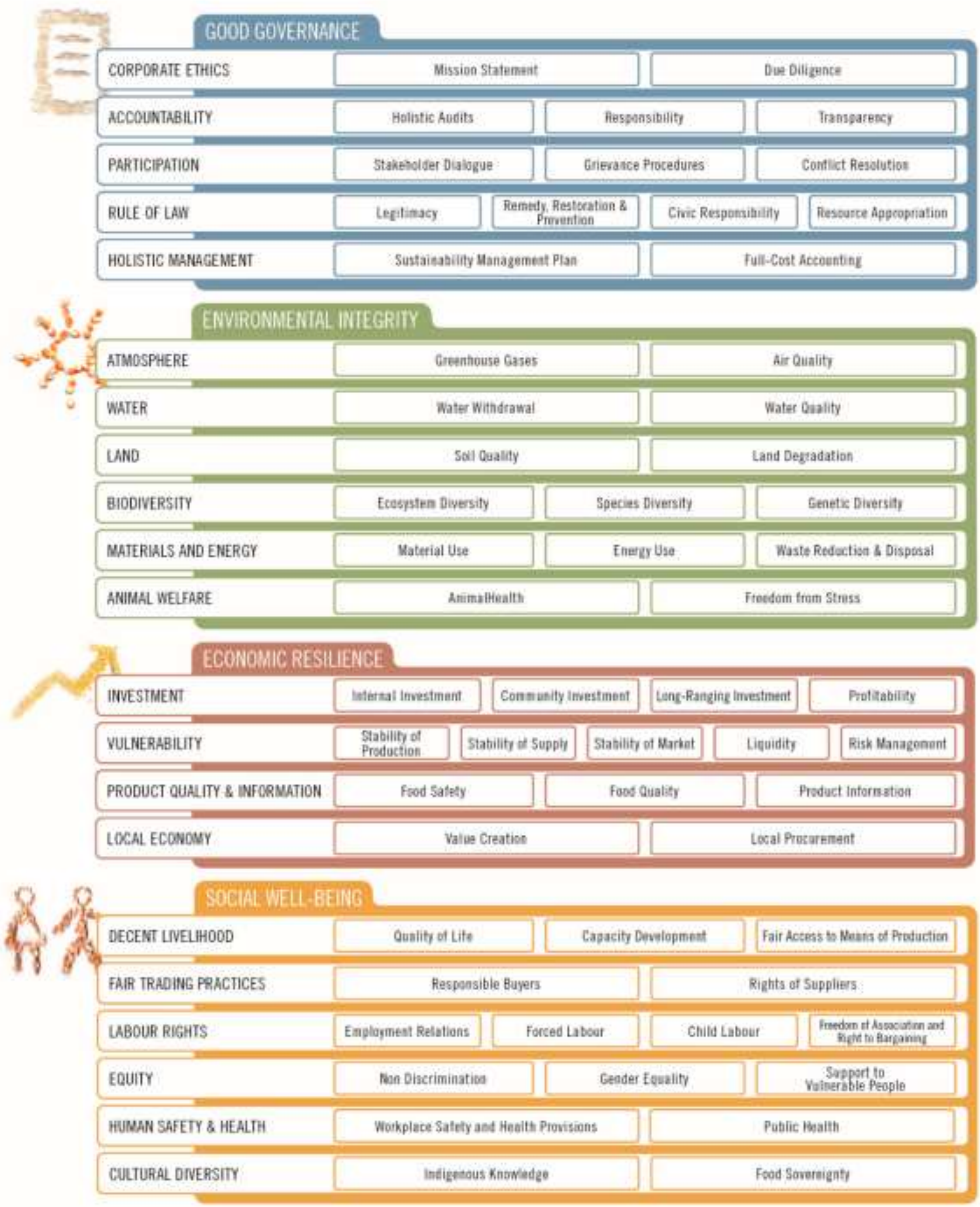

Figure 3.1 Overview of Sustainability Assessment of Food and Agriculture Systems (SAFA) dimensions, themes and subthemes. Source: Food and Agriculture Organization of the United Nations (FAO) 2014.

3.3.3 Application of SMART-Farm Tool in data collection and analysis

Empirical data for this study were collected in May and June 2016 in an assessment using the SMART-Farm Tool (Version 4.0). The farms were evaluated based on a subset of 318 indicators (from the SMART-Farm Tool pool of 327 indicators) that were found to be relevant for sample farms. Data were collected in face-to-face interviews during farm visits with the heads of the farm household or, in their absence, the most senior member of the farm household.

3.3.4 Data analyses of results of SMART-Farm Tool

This study uses the term ‘farm type/s’ to refer to the five categories or types of farms identified in the previous study (Kamau et al., 2018). The study further makes a distinction between farms that are certified and those that are not certified (i.e. certification status). The non-certified farms include organic non-certified, conventional and ‘organic-by-default’ farms.

Multivariate analysis of variance (MANOVA) and multiple linear mixed-effects models were used to test whether farm type (Types 1 to 5), farm certification status (organic certified versus non-certified) and county (Kajiado versus Murang’a) or the three factors combined had a significant impact on the assessed sustainability subthemes. Farm type, certification status and county were fixed factors, while the random term in the models was farm. If factors significantly impacted on a specific subtheme, LSD posthoc tests were performed to compare the means of the different factor levels (Papke and Woodridge 1996; Baum 2008).

For a meaningful interpretation of the results it is important to identify the factors driving the sustainability scores in these subthemes (Schader et al. 2016). Thus, the performance of indicators relevant for each subtheme and represented by the RI value was revisited. Generalized linear models with binomial family and logit link were used to examine the existence of significant differences in indicator sustainability performance using average RI scores with respect to farm type, certification status and county. However, since numerous indicators affected the performance of a given subtheme, we report and discuss only indicators with high impact weight (i.e. ≥ 0.6, where 0=least 1=highest).

3.4 Results and discussion

3.4.1 Overall sustainability performance

The overall sustainability performance of the smallholder farms in the two counties followed a similar pattern (Figures 3.2 to 3.5). The worst performance in all farms was in the dimension of Good Governance, especially in the themes Accountability and Holistic Management (Figure 3.2). In this dimension, the average performance of farms was poor with <36% degree of goal achievement (DGA) for the subthemes Mission Statement, Holistic Audits, Transparency, Civic Responsibility and Full-Cost Accounting irrespective of farm type, certification status or county (Figures 3.3A, 3.4A, 3.5A). This was mainly due to the failure to consider external costs in the accounting procedure, lack of an explicit sustainability plan, lack of farm certification in the use of agrochemicals as well as publicly disclosed written sustainability reports (Appendix B2).

Farm management and accountability

According to the SAFA Guidelines, the Holistic Management theme is concerned with the consideration of the external effects of the farm activities in accounting and decision-making, while the Accountability theme relates to disclosure and availability of correct and complete information about all aspects of the farm’s performance, which builds credibility of the farm enterprise (FAO 2014).

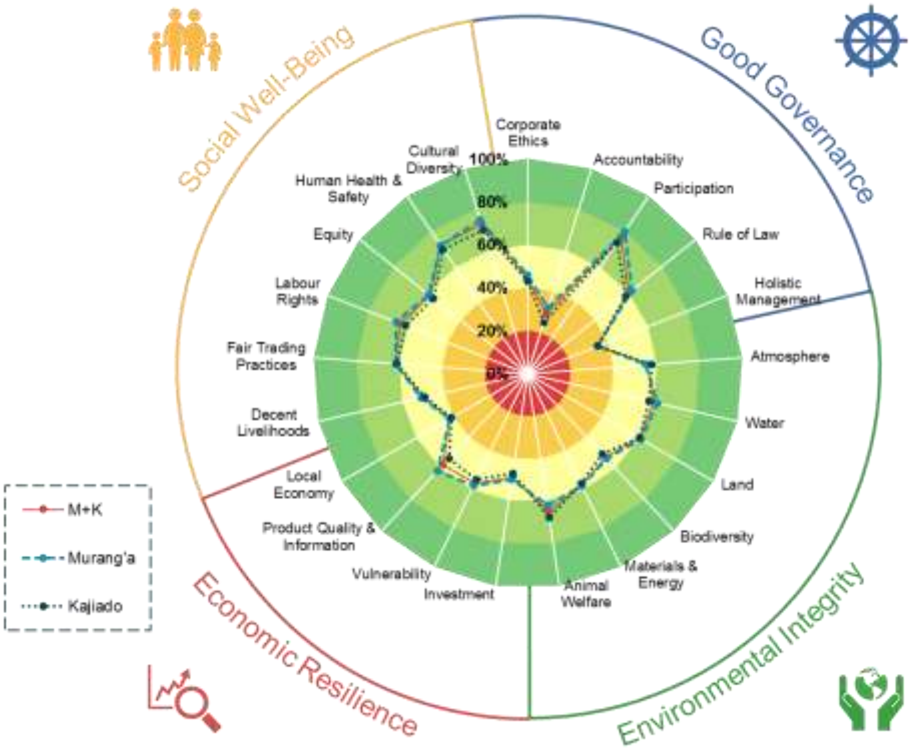

Figure 3.2 Overall average performance of farms in relation to counties across the four sustainability dimensions with respect to sustainability themes.

A similar poor performance in terms of Accountability and Holistic Management has been reported elsewhere, including in studies in developed countries (Schader et al. 2016; Landert et al. 2017). One of the contributing factors can be poor documentation (i.e. failure to keep records, inconsistent or scanty records, monitoring and evaluation), which has been identified as a major challenge for smallholder farms in Kenya, and which may limit the success of a farm as a business (Muriithi et al. 2014). This applies to both certified and non-certified farms, though the effect is more apparent in the former due to the complex paperwork required for certification and control (Sahm et al. 2013). The ability of all farmers to account, record and monitor their farm's activities can be knowledge intensive, which is often a challenge given that most of the farmers in this study have no formal education beyond high school, with an average of nine years schooling (Kamau et al. 2018). Other studies in Kenya reported poor education and literacy levels of farmers (e.g. Kabubo-Mariara, 2005; Gyau et al., 2016).

However, Kamau et al. (2018) found that education and literacy of farmers was not linked to the practice of certified OA, and that wealth played a more significant role. Contractual agreements are more common with wealthier farmers (Ton et al. 2018), but this does not necessarily imply that these farmers are skilled in bookkeeping, a prerequisite for organic certification (Raynolds 2000, 2004). Nevertheless, building of social capital, particularly for the less educated farmers, is important to enhance their profitability and economic sustainability.

Capacity Development

The other subtheme with overall very poor performance was Capacity Development in the dimension of Social Well-Being (DGA <22% irrespective of farm type, certification status or county; Figures 3.3D, 3.4D, 3.5D). This was mainly the result of limited training of farm workers in many aspects like the use of chemical farm products and access to advisory services (Appendix B2). According to the SAFA Guidelines, Capacity Development aims for empowerment of farmers, employees or farm workers to provide them with skills and knowledge and enable them to undertake their current and future duties (FAO 2014).

Training opportunities for smallholder farmers and their workers, including farmer-to-farmer extension programs, farmer field schools and demand-driven extension programs, exist in both Kajiado and Murang'a through government extension, non-governmental organizations (NGOs), research institutes and private companies. However, limited coordination, inadequate technical and personnel capacities and resources remain a challenge (Rees et al. 2000b; Davis and Place 2003; Mati 2008). Furthermore, information acquisition of farmers and utilization of the knowledge are heavily influenced by literacy levels, affordability, physical accessibility and connection of farmers with extension agents (Maumbe 2010; Thuo et al. 2014; Kamau et al. 2018).

In addition, the need for technical knowledge in farming, as observed in this study in terms of poor handling of chemicals, has been reported in various regions of Kenya, for instance with regard to technical information on input use, pest and disease management and irrigation technology (Rees et al. 2000b; Mati 2008; Omondi et al.

2014). Furthermore, management of farm input and soil fertility can be a major barrier to sustainability (Grenz et al., 2009). To fill such knowledge and skill gaps among farmers and their employees, better coordination and a stronger role of the national government in extension services without over-reliance on NGOs and the private sector, who can withdraw their services as they wish, is imperative (Davis and Place, 2003). Various capacity building initiatives have been claimed to be successful in filling these gaps such as demand-driven extension services (Ngigi et al. 2016), farmer-to-farmer training such as the volunteer farmer trainers (VFT) approach (Lukuyu et al. 2012; Kiptot and Franzel 2014) or the increased use of information communication technology for dissemination of agricultural information (Maumbe 2010).

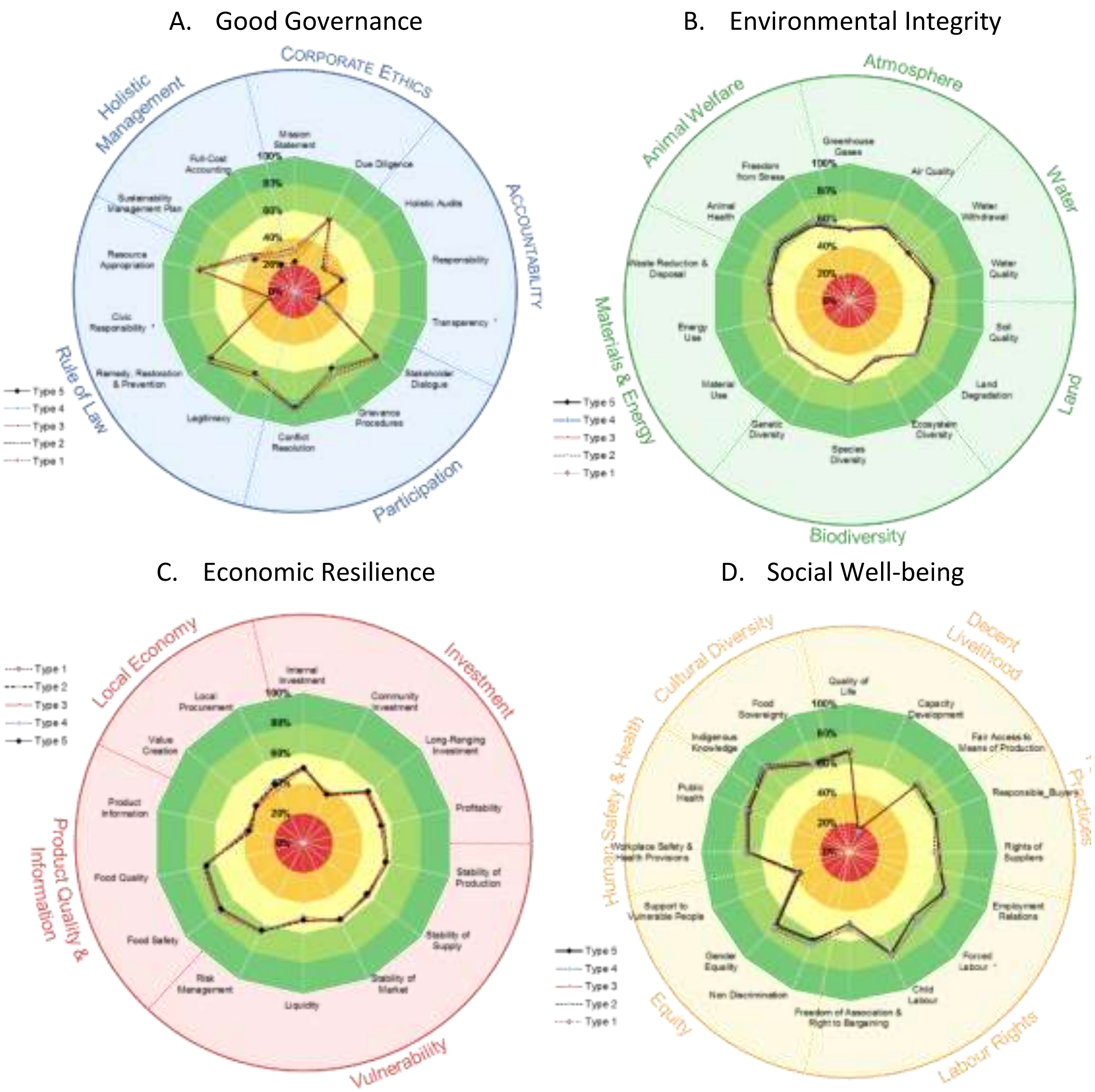

Figure 3.3 Average performance farms in relation to farm types with respect to sustainability themes and subthemes in the four dimensions of sustainability (* asterisk after subtheme title represents subthemes with significantly different sustainability performance).

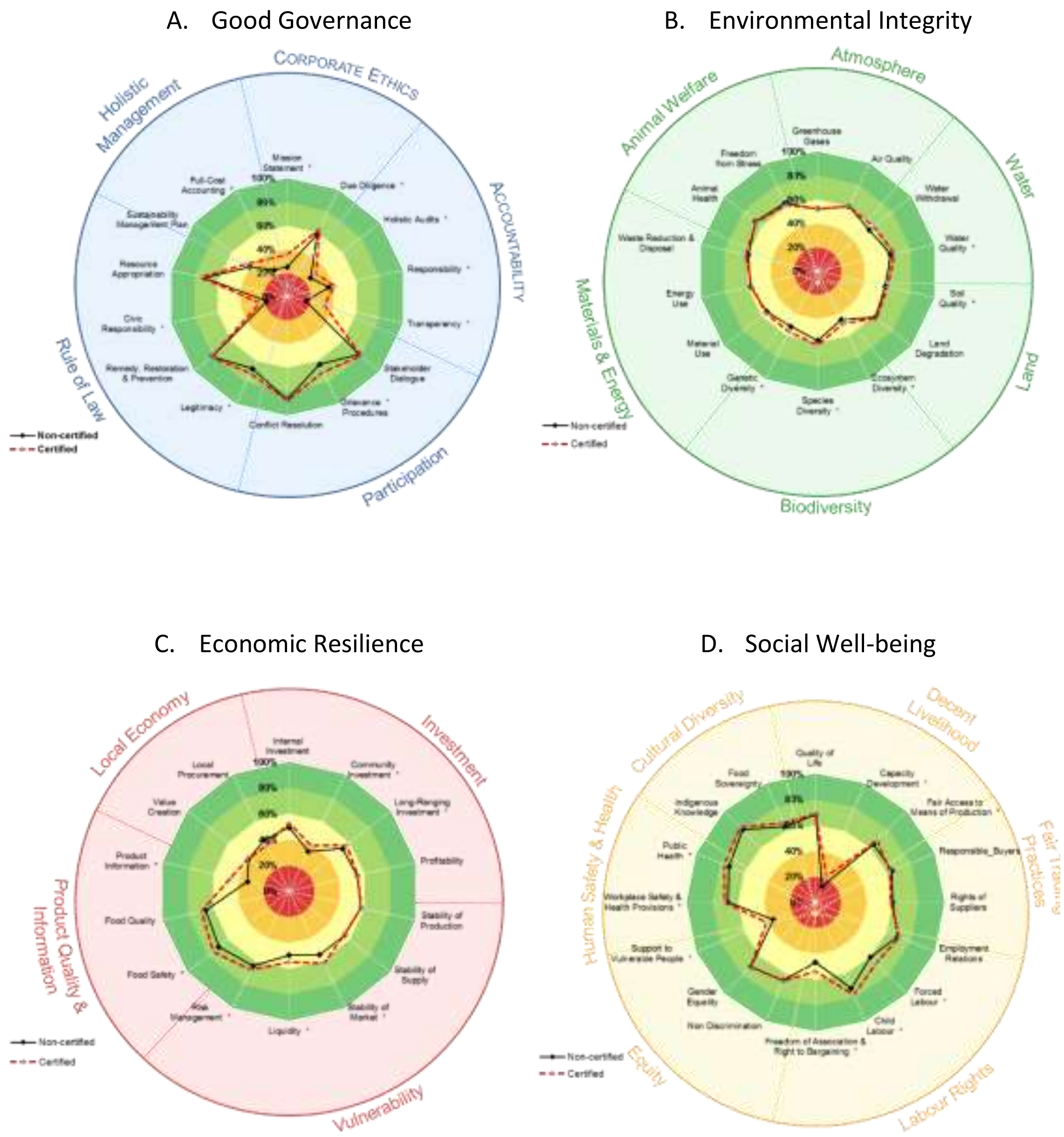

Figure 3.4 Average performance farms in relation to farm certification status with respect to sustainability themes and subthemes in the four dimensions of sustainability (* asterisk after subtheme title represents subthemes with significantly different sustainability performance).

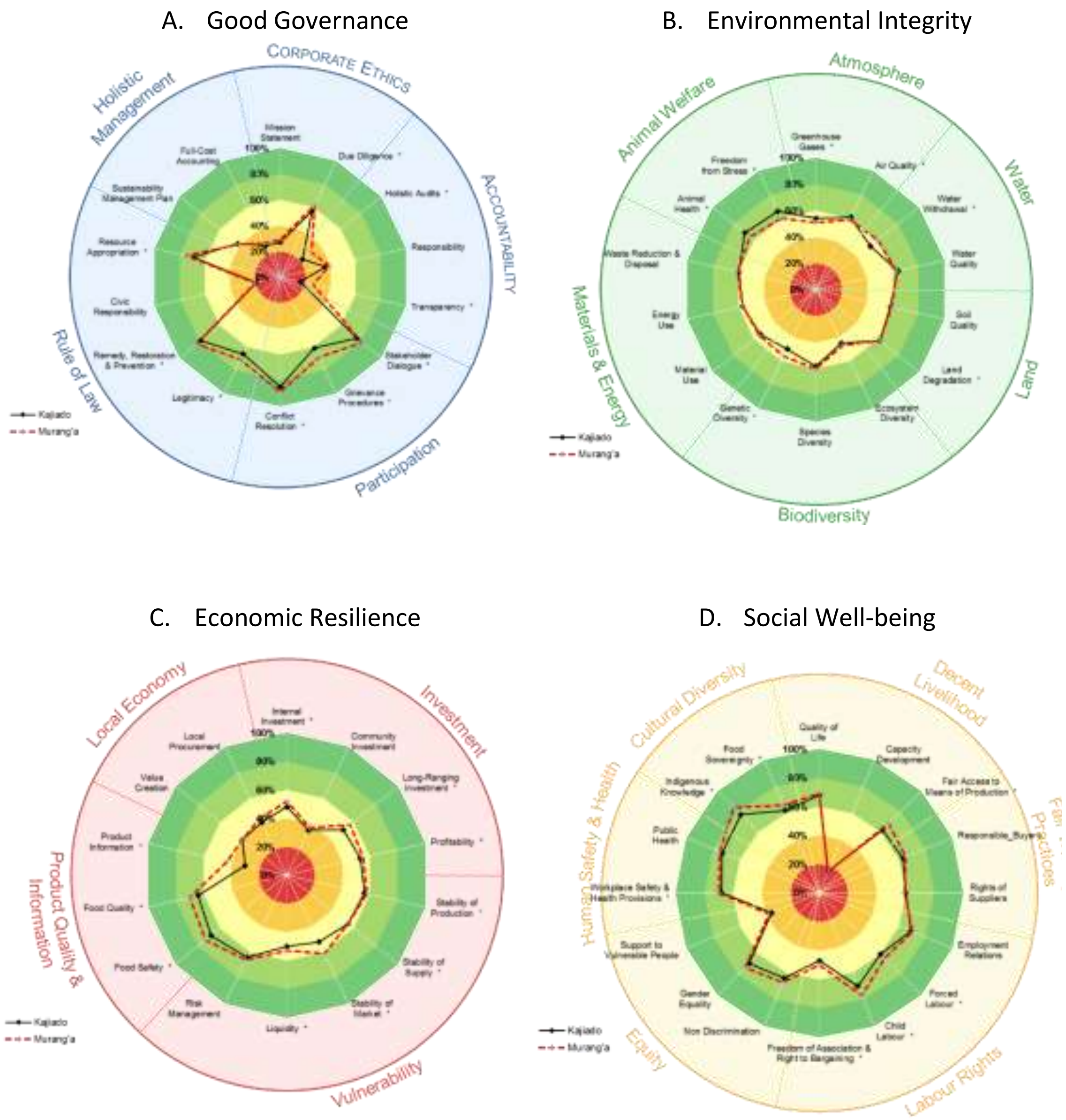

Figure 3.5 Average performance farms in relation to county with respect to sustainability themes and subthemes in the four dimensions of sustainability (* asterisk after subtheme title represents subthemes with significantly different sustainability performance).

3.4.2 Comparison of farm sustainability performance

In general, there were no major differences between the five farm types, except in the subtheme Forced Labor (Figure 3.3). However, certified farms performed better than non-certified ones (Figure 3.4), and farms in Murang'a performed better than those in Kajiado (Figure 3.5).

The MANOVA revealed no statistically significant differences in sustainability performance for the subthemes between the five farm types (Pillai's Trace =0.7, $F_{(232, 1172)} = 1.10$, $p=0.16$), but significant differences between the two counties (Pillai's Trace =0.7, $F_{(58, 290)} = 10.1$, $p< 0.001$), as well as the interaction between farm types and counties (Pillai's Trace =0.8, $F_{(232, 1172)} = 1.23$, $p=0.02$). Significant differences were also found between certified and non-certified farms (Pillai's Trace =0.4, $F_{(58, 296)} = 3.75$, $p< 0.001$), the two counties (Pillai's Trace =0.6, $F_{(58, 296)} = 8.57$, $p< 0.001$), and the interaction between farm certification and counties (Pillai's Trace =0.3, $F_{(58, 296)} = 1.84$, $p<0.01$), (Table 3.1; Appendices B3 and B4). These significantly different subthemes are indicated by an asterix (*) in Figures 3.3, 3.4 and 3.5.

The findings of this study show patterns of sustainability performance for Kenyan smallholder farms and key differences between organic certified and non-certified farms as well as between Murang'a and Kajiado. However, because no major differences in the sustainability of the five farm types were found, we do not discuss these results in detail. In the appendices B10 and B11, the indicators influencing these results are described in relation to the themes and subthemes and the objectives of the SAFA Guidelines. For a summary of high-impact indicators that contributed to major differences in subtheme scores with respect to certification status, farm type and county (see details in Tables 3.2, 3.3 and 3.4 ; Appendices B5, B6 and B7)

Table 3.1 Means of degree of goal achievement (DGA) for each subtheme by certification status and county, and significance levels for differences (letters indicate significant differences at p<0.05, ns = not significant). Cell colors indicate subthemes belonging to the same sustainability dimension. Significance levels of subtheme scores for the five farm types and interaction effects can be found in Appendices B3, B4, B8 and B9.

	Certification Status			County			Certification Status and County				
Sub-theme	p	Certified	Non-certified	p	Murang'a	Kajiado	p	Certified × Murang'a	Certified × Kajiado	Non-certified × Murang'a	Non-certified× Kajiado
Mission Statement	p<0.05	35.7a	27.1b	ns	30.6a	32.2a	ns	34.1a	37.2a	27a	27.3a
Due Diligence	p<0.001	64.1a	59.2b	ns	62.7a	60.7a	p<0.01	63.3a	64.9a	62.1a	56.4b
Holistic Audits	p<0.05	31.8a	27.1b	p<0.05	31.6a	27.3b	p<0.001	29.7a	33.9a	33.5a	20.6b
Responsibility	p<0.01	42.5a	36.8b	ns	39.1a	40.2a	p<0.01	39a	45.9	39.3a	34.4b
Transparency	p<0.001	31.1a	17.2b	p<0.001	27.9a	20.5b	ns	34.5a	27.7b	21.2a	13.2b
Stakeholder Dialogue	ns	80.7a	78.1a	ns	80.4a	78.4a	p<0.01	79.3a	82a	81.4a	74.8b
Grievance Procedures	p<0.001	69.4a	63.5b	p<0.001	69.6a	63.3b	ns	70.9a	67.9a	68.3a	58.8b
Conflict Resolution	ns	87.8a	86.8a	ns	88.5a	86.2a	p<0.05	86.9ab	88.8b	90.1b	83.6a
Legitimacy	p<0.01	71.3a	67.8b	p<0.01	71.6a	67.5b	ns	72.7a	69.9a	70.5a	65.1b
Remedy, Restoration & Prevention	ns	81.3a	81.5a	ns	82.7a	80.1a	ns	81.4ab	81.3ab	84.1b	78.8a
Civic Responsibility	p<0.01	26.4a	18.2b	ns	20.3a	24.2a	p<0.01	19.9a	32.8	20.8a	15.7a
Resource Appropriation	ns	74a	72a	p<0.01	75a	71b	p<0.01	73.8a	74.1a	76.2a	67.8b
Sustainability Management Plan	ns	44.8a	41.1a	ns	41.6a	44.3a	ns	41.2a	48.4a	42.1a	40.2a
Full-Cost Accounting	p<0.05	35.7a	27.3b	ns	30.6a	32.4a	ns	34.1a	37.3a	27.1a	27.5a
Greenhouse Gases	ns	53.2a	52.6a	p<0.001	51a	54.8b	ns	51.1a	55.3b	50.9a	54.3b
Air Quality	ns	60.8a	60.2a	p<0.001	59a	61.9b	ns	59.2a	62.4b	58.9a	61.4b
Water Withdrawal	ns	58.7a	56.3a	p<0.001	60.4a	54.5b	ns	61.1c	56.3ab	59.8bc	52.8a
Water Quality	p<0.01	66.1a	63.2b	ns	64a	65.4a	ns	65.9a	66.4a	62.1b	64.4a
Soil Quality	p<0.05	60.2a	58.4b	ns	59.3a	59.3a	ns	60.2b	60.1ab	58.4a	58.4a

Table 3.2 continued

	Certification Status			County			Certification Status and County				
Sub-theme	p	Certified	Non-certified	p	Murang'a	Kajiado	p	Certified × Murang'a	Certified × Kajiado	Non-certified × Murang'a	Non-certified× Kajiado
Land Degradation	ns	63a	62.1a	p<0.05	61.9a	63.1b	ns	62.2ab	63.7b	61.6a	62.5ab
Ecosystem Diversity	p<0.01	49.1a	46b	ns	47.6a	47.5a	ns	48.9c	49.4bc	46.4ab	45.6a
Species Diversity	p<0.001	62.1a	58.8b	ns	60.4a	60.6a	ns	61.6b	62.7b	59.1a	58.5a
Genetic Diversity	p<0.001	56.1a	52.6b	p<0.01	55.9a	52.8b	p<0.05	56.5a	55.8a	55.4a	49.8b
Material Use	ns	56.4a	55.2a	ns	55.8a	55.8a	ns	56.5a	56.2a	55a	55.4a
Energy Use	ns	57.3a	58.2a	ns	57.5a	58a	ns	56.8a	57.7a	58.2a	58.3a
Waste Reduction & Disposal	ns	62.4a	60.4a	ns	61.4a	61.3a	ns	63.3b	61.5ab	59.6a	61.2ab
Animal Health	ns	67.1a	66.7a	p<0.001	63.8a	70b	ns	62.9a	71.3b	64.7a	68.6b
Freedom from Stress	ns	63.1a	63.2a	p<0.001	59.4a	66.9b	ns	58.2a	68b	60.5a	65.8b
Internal Investment	ns	52.4a	50.5a	p<0.05	52.7a	50.2b	ns	53.4b	51.5ab	52b	48.9a
Community Investment	p<0.001	39.8a	34.7b	ns	37.1a	37.4a	p<0.05	38.1bc	41.5c	36ab	33.3a
Long-Ranging Investment	p<0.05	57.5a	54.2b	p<0.05	57.2a	54.5b	p<0.01	56.8a	58.2a	57.7a	50.7b
Profitability	ns	53.6a	54.3a	p<0.01	55.2a	52.7b	ns	55.1bc	52.2a	55.3c	53.3ab
Stability of Production	ns	57.8a	58.1a	ns	58.5a	57.4a	p<0.05	57.4a	58.2ab	59.6b	56.5a
Stability of Supply	ns	55.5a	55.2a	p<0.05	54.3a	56.4b	p<0.01	53a	58c	55.5bc	54.9ab
Stability of Market	p<0.001	60.4a	55.3b	p<0.001	61.6a	54b	ns	65.1vv	55.6ab	58.1b	52.4a
Liquidity	p<0.05	53.1a	49.9b	p<0.05	53.6a	49.4b	ns	56.3b	49.9a	50.8a	48.9a
Risk Management	p<0.001	68.3a	64.9b	ns	66.3a	66.9a	p<0.05	67bc	69.5c	65.5ab	64.4a
Food Safety	p<0.001	74.8a	70.3b	p<0.05	73.8a	71.4b	ns	75.4b	74.3ab	72.2a	68.4b

Table 3.3 continued

	Certification Status			County			Certification Status and County				
Sub-theme	p	Certified	Non-certified	p	Murang'a	Kajiado	p	Certified × Murang'a	Certified × Kajiado	Non-certified × Murang'a	Non-certified× Kajiado
Food Quality	ns	69.1a	67.4a	p<0.05	69.8a	66.8b	ns	70b	68.3ab	69.5b	65.4a
Product Information	p<0.001	44.9a	33.6b	p<0.001	44.5a	33.9b	ns	48.7b	41a	40.3a	26.9b
Value Creation	ns	40.8a	40a	ns	40.1a	40.7a	p<0.01	38.9a	42.6b	41.2b	38.9a
Local Procurement	ns	40.4a	43.9a	ns	42.9a	41.4a	p<0.001	36.9a	43.8ab	48.9b	38.9a
Quality of Life	ns	69.1a	68a	ns	68.4a	68.6a	p<0.01	67.7ab	70.4c	69.2bc	66.8a
Capacity Development	p<0.001	23a	13.6b	ns	17.5a	19a	ns	20.2b	25.7b	14.8a	12.3a
Fair Access to Means of Production	p<0.05	68a	64.6b	ns	67.5a	65.1a	p<0.05	67.2a	68.8a	67.9a	61.4b
Responsible Buyers	ns	63.2a	64.2a	ns	63.9a	63.6a	p<0.001	61.3a	65.2bc	66.5c	62ab
Rights of Suppliers	ns	59.3a	59.8a	ns	58.3a	60.7a	p<0.01	55.9a	62.6b	60.8b	58.8ab
Employment Relations	ns	70.1a	69.1a	ns	70a	69.3a	ns	69.9b	70.4ab	70.1b	68.1a
Forced Labor	p<0.001	66.3a	60.2b	p<0.01	65.1a	61.4b	ns	67.5b	65.1ab	62.6a	57.7b
Child Labor	p<0.001	77a	72.5b	p<0.001	77.8a	71.7b	p<0.05	79b	75.1a	76.5a	68.4b
Freedom of Association and Right to Bargaining	p<0.001	54a	46.8b	ns	51a	49.7a	ns	53.6a	54.3a	48.3a	45.2b
Non Discrimination	ns	65.8a	65.8a	ns	66.4a	65.2a	ns	65.6a	66a	67.2a	64.5a
Gender Equality	ns	70.9a	71.5a	ns	72.2a	70.2a	ns	71.1a	70.7a	73.3a	69.7a
Support to Vulnerable People	p<0.001	41.4a	35.6b	ns	38.3a	38.7a	ns	40.1b	42.8b	36.6a	34.7a
Workplace Safety and Health Provisions	p<0.01	71a	68b	ns	69.7a	69.3a	p<0.05	70.1a	71.9a	69.4a	66.7b
Public Health	p<0.001	77a	73.2	ns	75a	75.2a	ns	76.4b	77.7b	73.7a	72.7a
Indigenous Knowledge	ns	82a	80.4a	p<0.01	83.9a	78.5b	ns	83.7b	80.3ab	84.2b	76.6a
Food Sovereignty	ns	66.8a	64.8a	ns	66.5a	65.1a	p<0.01	65.5a	68.1a	67.5a	62.1b

Table 3.2 Mean sustainability scores (i.e. average RI values) of indicators related to land and crop management with significant differences between certified and non-certified farms.

Indicator	p	Certified	Non-certified
Use of chem. synthetic seed dressings	p<0.001	18.9a	11.4b
Agro-forestry systems	p<0.01	8.8a	6.4b
Permanent grasslands: share of agricultural area	p<0.05	3.9a	1.9b
Ecological compensation areas: share of agricultural land	p<0.001	15.6a	11.7b
Permanent grasslands: extensively managed	p<0.01	3.4a	11.8b
Pesticides: toxic for bees	p<0.05	60a	55.1b
Pesticides: toxic for aquatic organisms	p<0.05	60.7a	54.9b
Soil degradation: measures taken to counter degradation	p<0.05	30.5a	27.2b
Determining fertilizer requirements	p<0.05	8.4a	6.4b
Antibiotics from livestock in fertilizers	p<0.05	27.5a	23.7b
Soil improvement	p<0.001	26.7a	33.9b
Mineral potassium fertilizers	p<0.001	4.6a	16b
Pesticides: number of active substances	p<0.05	65.3a	59.5b
Pesticides: chronic toxicity	p<0.05	68.9a	63.2b
Harmful substances in phosphate fertilizers	p<0.05	11.6a	6.6a

3.4.3 Indicators responsible for differences in sustainability performance of farms

Differences in land and crop management practices of certified and non-certified farms

Certified organic farms showed limited to no usage of agrochemicals and handled their waste better than the non-certified ones, which led to improved performance in subthemes related to soil quality, biodiversity and waste disposal (Table 3.3; Appendix B5). They had a significantly lower use of synthetic seed dressing, pesticides toxic to bees and aquatic organisms, annual usage of pesticides with a high number of active substances, and pesticides that are very persistent in the soil (half-life >180 days) according to the PAN Pesticide Database (Kegley et al. 2016). Additionally, these farms had better disposal techniques/procedures for waste from pesticides and veterinary drugs than non-certified farms. Certified organic farms were also significantly less likely to use phosphorous fertilizers or phosphate rock, which are often contaminated with harmful substances, e.g. heavy metals, performed more soil tests to determine fertilizer requirement, were less likely to apply manure from livestock treated with antibiotics on cultivated areas, had more agroforestry systems, and cultivated more scattered fruit trees than non-certified farms.

However, there were no significant differences between certified and non-certified farms in terms of the quantity of mineral nitrogen and phosphorous fertilizer used per hectare per year. Actually, the use of mineral potassium fertilizer in certified farms was significantly higher than in non-certified ones. The two main patterns observed in mineral fertilizer use in certified and non-certified farms were: (i) either both did not use mineral fertilizer and only pesticide use was the main differentiation or (ii) both used mineral fertilizer in varying amounts. The second pattern could be because some farms were partially certified, implying that agrochemicals were applied to a given crop area within the farm, but a buffer zone separated the area where certified crops were grown from other parts of the farm.

Moreover, there were no significant differences between certified and non-certified farms in terms of recycling of crop residues, use of compost and farmyard manure, humus balance, prophylactic use of antibiotics for livestock, and use of GMO crops or feedstuff (Table 3.2). This implies that farms were applying almost similar management practices irrespective of certification status or OA practice as shown by the lack of major differences in the five farm types.

These finding are similar to those of previous studies on the sustainability of organic and non-organic smallholder farms types in Africa, e.g. De Jager et al. (2001) in Machakos County in eastern Kenya who found no significant differences between low external input organic and conventional farming in terms of soil health. Both systems were found to be based on soil mining, especially in terms of nitrogen, unless the organic farmers reduced nutrient losses.

Organic production is knowledge intensive, and in general the provision of a sufficient nutrient supply is a major challenge for OA (Sahm et al. 2013). For smallholders, who are often resource constrained and commonly employ poor farming practices leading to soil nutrient mining (Mulinge et al. 2016) and consequently yield gaps (Tittonell and Giller 2013), OA could prove to be even more of a challenge.

However, as also reported in other studies, our results show the potential of OA to increase biodiversity and improve soils and water quality through the proper management of pesticides and veterinary drugs as well as incorporation of trees on agricultural land (Seufert and Ramankutty 2017; Muller et al. 2017).

Table 3.3 Average RI values of high impact indicators (weight>0.6) for certified and non-certified farms and significance levels (letters indicate significant differences at $p<0.05$, ns = not significant). Cell colors indicate subthemes belonging to the same sustainability dimension.

Dimension	Indicator	p	Certified	Non-certified
Good Governance	Proactive support of disadvantaged groups	p<0.05	53.6a	46.4b
	Professional agricultural accounts	ns	28.5a	28.5a
	Workers: legally binding contracts	ns	59.4a	60.7a
	Proportion of environmentally certified products	p<0.001	20.6a	8b
	Waste disposal: pesticides and veterinary medicines	p<0.001	61.4a	48b
	Transparency of production	p<0.001	26.6a	8.5b
	Mineral potassium fertilizers	p<0.001	4.6a	16b
	Animal welfare standards (slaughter)	p<0.05	32a	28b
Environmental Integrity	Buying new animals	ns	27.3a	27.7a
	Pig keeping: quarantine section	p<0.001	15.5a	8.7b
	Permanent grasslands: extensively managed	p<0.01	3.4a	11.8b
	Polishing piglet teeth	ns	18.2a	18a
	Mineral potassium fertilizers	p<0.001	4.6a	16b
	Waste disposal: pesticides and veterinary medicines	p<0.001	61.4a	48b
	Number of scattered fruit trees	ns	22.4a	20.4a
	Recycling of paper/cardboards	p<0.001	20.2a	13b
	Wastewater disposal	ns	44.1a	42.1a
	Water use efficiency	ns	51.3a	50.7a
	Access to pasture for ruminants	p<0.001	4.1a	9.6b
	Injuries of pigs	ns	33.6a	33.6a
	Mutilation: use of anaesthetics and analgesics	ns	22.7a	27.4a
	Animal welfare standards (slaughter)	p<0.05	32a	28b
	Loss of agricultural products (food waste)	p<0.001	40.4a	49.7b

Table 3.3 continued

Dimension	Indicator	p	Certified	Non-certified
Economic Resilience	Proportion of environmentally certified products	p<0.001	20.6a	8b
	Transparency in production	p<0.001	26.6a	8.5b
	Workers: training in use of plant protection and animal treatment products	ns	63.3a	60.5a
	Further training for farm staff	p<0.001	26.5a	15.1b
	Long-term investments	p<0.05	52.5a	44.4b
	Diversification of income	p<0.001	46.8a	27.2b
	Proportion of products meeting social standards	p<0.001	17.9a	7.2b
	Professional agricultural accounts	ns	28.5a	28.5a
	Buying new animals	ns	27.3a	27.7a
	Diversification of sales	p<0.05	63.4a	53.4b
	Access to pasture for ruminants	p<0.001	4.1a	9.6b
	Yield loss	p<0.001	25.9a	39.1b
	Injuries of pigs	ns	33.6a	33.6a
Social Well-Being	Further training for farm staff	p<0.001	26.5a	15.1b
	Access to advisory services	p<0.05	57.5a	51b
	Workers: legally binding contracts	ns	59.4a	60.7a
	Workers: permanent workforce	p<0.001	5.6a	2.1b
	Workers: social protection	p<0.001	17.2a	7.7b
	Proactive support of disadvantaged groups	p<0.05	53.6a	46.4b
	Waste disposal: pesticides and veterinary medicines	p<0.001	61.4a	48b
	Wastewater disposal	ns	44.1a	42.1a
	Pig keeping: quarantine section	p<0.001	15.5a	8.7b

Differences in land and crop management practices of Kajiado and Murang'a farms

Fewer measures to improve soil humus, a lower number of scattered fruit trees and perennial crops as well as limited measures to improve soil or counter degradation contributed to the poorer sustainability performance of the farms in Kajiado compared to that in Murang'a. However, on Murang'a farms, the lower share of land under direct seeding negatively affected sustainability (Table 3.4 and Appendix B7).

Similarly, a low adoption of soil conserving management practices has been reported in other ASAL regions of Kenya, concurrent with low agricultural productivity mainly due to limited access to productive assets including land, inputs, farm machines, markets and information (Mutuku et al. 2017). Furthermore, although cultivation of perennials is associated with benefits such as reduction in soil erosion, environmental pollution, and soil degradation, these benefits are long term (Pimentel et al. 1997; Culman et al. 2013) and may not be attractive to resource-constrained farmers, who struggle to meet their daily needs, especially in ASAL regions like Kajiado where erratic weather conditions are prevalent (Campbell 1984). Direct seeding is associated with positive effects such as improved labor and water use efficiencies (Bhushan et al. 2007). It is argued to be more sustainable because it implies minimal disturbance to the soil, hence offsetting soil degradation (Kassam et al. 2009). The lower share of land with direct seeding in Murang'a could be attributed to the predominant crops grown there like tea, coffee, fruit trees and tubers, which are mainly cultivated by transplanting (GoK 2009; Oduol et al. 2017).

Table 3.4 Average RI values of high impact indicators (weight>0.6) for farms in Murang'a and Kajiado counties and significance levels (letters indicate significant differences at p<0.05, ns = not significant). Cell colors indicate subthemes belonging to the same sustainability dimension.

Dimension	Indicators	p	Murang'a	Kajiado
Good Governance	Prevention of resource conflicts	p<0.001	57.6a	45.2b
	Proportion of environmentally certified products	p<0.001	20.1a	3.9b
	Proportion of products meeting social standards	p<0.001	17.9a	3.3b
	Humus formation: humus balance	p<0.001	33a	25.8b
	Waste disposal: pesticides and veterinary medicines	p<0.001	56.9a	46.8b
	Information on water availability	p<0.001	33.7a	24.3b
	Transparency of production	p<0.001	21.5a	6.8b
	Communication with stakeholder groups	ns	51.8a	63.3a
	Proactive support of disadvantaged groups	p<0.05	46b	51.5a
	Professional agricultural accounts	ns	20.5a	35.4a
Environmental Integrity	Polishing piglet teeth	ns	16.7a	20.2a
	Number of scattered fruit trees	p<0.001	28.7a	12.6b
	Hybrid livestock (poultry, pigs)	p<0.05	23.4a	18.5b
	Electricity consumption per ha	p<0.001	27.8a	18.5b
	Information on water availability	p<0.001	33.7a	24.3b
	Irrigation: water consumption per ha	p<0.001	52.1a	39.2b
	Irrigation: precipitation measurement	p<0.001	46.5a	28.4b
	Covered slurry stores (or stable natural crust)	p<0.001	12.5a	31b
	Arable land: share of direct seeding	p<0.001	14a	33.4b
	Access to pasture for ruminants	p<0.001	0.4a	20.8b
	Share of dehorned ruminants	p<0.001	11.1a	29b
	Cleanness of livestock / housing	p<0.001	36.3a	50.2b

Table 3.4 continued

Dimension	Indicators	p	Murang'a	Kajiado
	Animal-friendly housing system	p<0.001	45a	57.7b
	Number and quality of drinking points	p<0.001	48.5a	58.6b
	Daily outdoor access for animals	p<0.001	5a	25.4b
	Buying new animals	ns	27.8a	27.5a
	Pig keeping: quarantine section	ns	10.5a	11a
	Loose-housing system	p<0.05	19.7a	28.3b
	Materials to keep animals busy	p<0.01	15.3a	25.2b
	Permanent grasslands: mowing frequency	ns	22.9a	20.1a
Economic Resilience	Proportion of environmentally certified products	p<0.001	20.1a	3.9b
	Product returns	p<0.001	65.5a	39.6b
	Food safety standard	ns	5.6a	0b
	Transparency of production	p<0.001	21.5a	6.8b
	Long-term investments	p<0.001	52a	41.2b
	Soil degradation: measures to counter degradation	p<0.001	32.9a	23.2b
	Soil improvement	p<0.001	36.7a	26.1b
	Number of scattered fruit trees	p<0.001	28.7a	12.6b
	Land ownership	p<0.001	56.6a	49.2b
	Proportion of products meeting social standards	p<0.001	17.9a	3.3b
	Commercially viable size of main business unit(s)	p<0.001	70.2a	55.8b
	Length of customer relationships	p<0.001	40.3a	25.8b
	Hybrid livestock (poultry, pigs)	p<0.05	23.4a	18.5b
	Number of perennial crops	p<0.001	13.4a	0.4b
	Daily outdoor access for animals	p<0.001	5a	25.4b

Table 3.4 continued

Dimension	Indicators	p	Murang'a	Kajiado
	Access to pasture for ruminants	p<0.001	0.4a	20.8b
	Buying new animals	ns	27.8a	27.5a
	Credit limit	p<0.05	18.7a	31.3a
	Professional agricultural accounts	ns	20.5a	35.4a
	Market challenges	p<0.001	41.5a	50.5b
	Number of scattered fruit trees	p<0.001	28.7a	12.6b
	Arable land: share of direct seeding	p<0.001	14a	33.4b
	Number and quality of drinking points	p<0.001	48.5a	58.6b
Social Well-Being	Prevention of resource conflicts	p<0.001	57.6a	45.2b
	Proportion of products meeting social standards	p<0.001	17.9a	3.3b
	Locally adapted livestock breeds	p<0.001	37.2a	31.8b
	Hybrid livestock (poultry, pigs)	p<0.05	23.4a	18.5b
	Waste disposal: pesticides and veterinary medicines	p<0.001	56.9a	46.8b
	Access to medical care	p<0.01	54.8a	43.6b
	Cleanness of livestock / housing	p<0.001	36.3a	50.2b

Despite benefits linked to the cultivation of scattered fruit trees such as increased biodiversity and soil nutrients, provision of fruits, wood products and fodder, this is less prevalent in smallholder farms in East and Central Africa than in Sahelian and southern parts of the continent (Manning et al. 2006; Jama et al. 2008). Jama et al. (2008) identified the lack of improved varieties and markets as major constraints limiting the adoption of fruit trees in smallholder farming in ASAL regions in SSA, which they argued could contribute to improved income and nutritional security. Cultivation and cropping practices affect soil physical, chemical and biological characteristics, consequently affecting soil fertility, biodiversity and plant productivity, thus ultimately influencing the sustainability of a farm (Dalal and Mayer 1986; Adamtey et al. 2016; Delgado-Baquerizo et al. 2017) thereby underlining the need for improved adoption of resource conserving practices.

Farm enterprise

The economic resilience of organic certified farms was significantly enhanced by more long-term investments in farm infrastructure and land, more diversified sales and income sources, but significantly reduced by higher yield losses compared to non-certified farms (Table 3.4 and Appendix B5).

Organic agriculture is normally associated with diversification of crops, e.g. through intercropping and crop rotation (Rasul and Thapa 2003a; Singh and Maharjan 2017). Our findings also imply more diversified livelihoods among the certified farms, possibly because certified farms were wealthier. Previous studies in Kenya and beyond showed a positive relationship between income diversification and wealth in smallholder farms, irrespective of certification status (Mutoko et al. 2014; Ponisio et al. 2015; Kuivanen et al. 2016a). In general, diversification is positively associated with wealth accumulation and reduction to various risks (Barrett et al. 2001a; Davis et al. 2017), but the these benefits can be undermined by yield losses, which, as mentioned earlier, is a major challenge for smallholders in SSA. Moreover, Davis et al. (2017) emphasized the need to continuously invest in farms to allow them to develop into commercially viable business enterprises, which could contribute to better economic sustainability.

Regarding county differences, the significantly higher commercial viability of the main enterprise on the farm, longer lengths of customer relationships, and lower product returns from customers in Murang'a contributed to higher economic sustainability there. However, significantly lower levels of credit access and less awareness of future market challenges reduced the economic sustainability of those farms (Table 3.3, 3.4 and Appendix B7).

The limited knowledge of market challenges in Murang'a may be attributed to poorly developed agricultural input and output markets (Ekbom et al. 2001). The avocado market in Murang'a, for instance, is dominated by middlemen (Oduol et al. 2017). In addition, low credit uptake by smallholder farmers in Murang'a has been reported by other studies, even for farmers with land title deeds as collateral due to poor credit markets. There are high interest rates on agricultural loans and risk of land appropriation in case of default (Mburu et al. 2012; Ayuya et al. 2015; Ndukhu et al. 2016; Gyau et al. 2016). In Kajiado, however, credit access is less of a challenge, as it is more urbanized and thus has a higher concentration and diversity of formal banks (Mburu et al. 2012).

Despite Kenya's relatively well-developed banking sector, banks often view farming as a highly risky field to invest in (Njenga et al. 2011). There is a need to provide sound loan products to finance agriculture by removing barriers to both lenders and borrowers. One way, especially for asset-poor farmers, is through group-based access (Ngigi et al., 2016). Furthermore, to increase their competitiveness, smallholders in Murang'a need to be more involved in agricultural value chains. Horizontal and vertical cooperation between farmers, various actors and service providers with the help of intermediaries has been argued as one way of overcoming these challenges (Kilelu et al. 2017). In addition, the well-developed information and communication technology sector in Kenya offers an opportunity for improved information access with respect to prevailing and future market challenges and opportunities (Maumbe 2010; Krone et al. 2016).

Farmer and employee welfare

Certified organic farms provided significantly greater for disadvantaged groups, had more permanently employed workers and workers with social protection than non-certified farms, although the proportion of these workers was very low in both cases. In addition, farms in Kajiado showed significantly better proactive support for the disadvantaged though these had significantly poorer access to health care than in Murang'a (Table 3.3).

The limited social security in Kenyan smallholder farming observed in this study was also reported by Grenz et al. (2009), who used RISE to assess sustainability in farms in the Laikipia region of Kenya. Terms of employment are important in determining the level of support to workers. For instance, Dolan et al. (2003) found that permanent employees in the cut-flower industry in Kenya had higher job security and better fringe benefits. Informal wage workers, who are mostly women and the youth (i.e. below 35 years), make up > 60% of the labor force in rural Kenya, and are largely affected by little or no social security, low wages and lack of essential employment rights such as paid leave (Barrientos et al. 2002; Dolan 2004; Keizi 2006; Hope 2011). Although Kenya has a national safety net program that targets the poor and vulnerable people like those with severe disabilities, older persons, and children (World Bank 2013, 2017), as well as a cohesive social protection policy, it is observed that poor institutional coordination and management and limited awareness among workers hinders their success (Mathauer et al. 2008; ILO 2016). Therefore, stronger linkages between institutions involved in social protection and empowering of workers have the potential to improve this situation.

Although it may be a challenge for poor smallholder farmers to provide social protection for their workers, workers themselves can get involved in the national programes for medical care and retirement benefits that already exist in Kenya. Keizi (2006) also emphasized the need of employee training on benefits of social security as well as obliging employees to contribute to social security programs, which, the author argues, would overcome their short-term mentality that hinders them from contributing to existing pension programs. The author also suggests tax incentives to induce savings by low-income groups like women. Similarly, Dolan (2004) proposed enforcement of voluntary or mandatory social protection for farm workers.

The results of this study reveal that organic certification could play a role in improving this situation, although its implications in smallholder systems remains unclear (Mitiku et al. 2017). It has been argued that, compared to the other dimensions of sustainability, some aspects of social sustainability like workers' salaries and benefits have not received much attention in organic certification (Reganold 2013) as its focus has been traditionally more on environmental rather than social aspects. However, members following IFOAM specifications have to maintain key social standards that improve the well-being of farmers and farm workers (Raynolds et al. 2007).

In addition, our findings show that certified organic farms had significantly better sustainability performance than non-certified ones in terms of training of farm workers and access to advisory services. This can be explained by the fact that NGO's and private companies that are in contractual arrangements with these certified farms also offer training and advisory services to the farmers and their workers. Hence, although capacity development was generally found to be poor, the findings indicate certain benefits of organic certification for increased human and social capital, which collaborate results from earlier studies in Kenya (Barrett et al. 2001b; Bolwig et al. 2009; Ndungu et al. 2013; Ayuya et al. 2015).

Animal husbandry

Animal welfare, in terms of health and freedom from stress, did not differ significantly between certified and non-certified organic farms (Table 3.1). However, major differences in animal husbandry practices between counties were observed. In Murang'a, it was a challenge for smallholder farms to achieve good performance for animal welfare due to lack of clean and animal-friendly housing, limited drinking points and outdoor access, dehorning of animals, lack of quarantine areas, limited access to pasture, poor animal slaughter standards, and lack of materials to keep animals busy. In addition, the farms there had a significantly higher extent of uncovered slurry stores. In general, Kajiado farms reared a significantly lower proportion of hybrid livestock compared to those in Murang'a (Table 3.4).

Such regional differences have been documented before. For instance, studies in Murang'a found that animals were rarely let loose, and were mainly confined to their designated housing or tethered. This was attributed to years of land fragmentation leading to small land holdings (Ovuka 2000b; Ekbom et al. 2001), unlike in Kajiado where average landholdings are larger and outdoor animal movement is less restricted (Odhong et al. 2014). As in our study, Lekasi et al. (2003) also reported poor animal housing conditions in Murang'a, and noted that the predominant livestock shelter was a semi-traditional enclosure with a partial roof, soil floors with organic crop residue as bedding and a poor urine drainage. This means that animals and workers are predisposed to poor air quality, parasites, infections, dust and mould. In addition, the uncovered slurry in the county is a source of the greenhouse gases methane and nitrous oxide (Mgbenka 2013). Although Kenya has a comprehensive legal animal welfare framework (Masiga and Munyua 2005), the findings of our study suggest that there is an urgent need to improve animal welfare through better livestock management practices, especially in densely populated highland regions like Murang'a.

Limited rearing of hybrid livestock in Kajiado has also been reported. For instance, Otieno (2012) found that pastoralists predominantly kept local breeds like Zebus because they found them more adapted to ASAL conditions, while the more diversified farmers tended to rear hybrid cattle. Local breeds are argued to have lower productivity (Otieno 2012), while hybrids are more vulnerable to the stressing environmental conditions found in ASAL regions. In general, agrobiodiversity reduces vulnerability to pests and diseases as well as to other environmental stressors like drought (Thrupp 2000; Di Falco and Chavas 2006; Altieri 2009). These trade-offs highlight the need to find a balance between short-term productivity and long-term resilience.

Conflict and land ownership and investment

Our results indicate significantly poorer mechanisms to prevent conflicts in resource use when farm ownership was unclear or disputed in Kajiado, where significantly less secure land tenure rights exist than in Murang'a (Tables 3.3 and 3.4).

There is evidence of land-use conflicts in Kajiado associated with resource competition between herding, crop cultivation and wildlife, which in turn is the result of demographic pressure, land subdivision and climate change (Campbell et al. 2000; Njiru 2012; Ogutu et al. 2014). Land ownership in Kajiado, previously belonging to semi-nomadic Maasai, is gradually transforming due to immigration, from communal ownership to freehold, with privatization at communal or individual household level driving well-documented land-use conflicts (Campbell et al. 2000; Kabubo-Mariara et al. 2009). Although our study did not determine a connection between conflict and land tenure, malfunctioning land tenure in Kajiado is associated with resource-use conflicts. For instance, privatization of land in Kajiado has been linked to conflict over sale and payment of land. In addition, human-wildlife conflicts in the region are increasing as human settlements encroach on wildlife habitats. These conflicts are exacerbated by periods of drought, damage to crops by livestock from herders, and conflicts over water use albeit with regional variations (Campbell et al. 2000; Ogutu et al. 2014). In Murang'a, however, land rights are overall more secure and based on family and clan affiliation systems where land is passed down through inheritance or freehold. In both systems, whether clan or freehold, common resources like woodlands, grazing land and water resources are clearly demarcated and less disputed (Mackenzie 1989; Ekbom et al. 2001).

Land-tenure insecurity could partly explain the limited long-term investments in soil improvement on the farms in Kajiado (Table 3.3). The positive association of secure land tenure and long-term investments in soil and water conservation as well as in farm infrastructure is well documented in literature (Shepherd and Soule 1998; Gebremedhin and Scott 2003; Fraser 2004), and also in Kajiado (Kabubo-Mariara, 2005). In our previous study, we found that the practice of OA was associated with secure land tenure (Kamau et al., 2018). Challenges to land-tenure security greatly contribute to poverty and food insecurity in SSA (Radwan 1995; Salami et al. 2010; Stellmacher 2015), whereas improved access to land and physical assets can contribute to poverty reduction (Radwan, 1995). Therefore, the currently ongoing land reform in Kenya needs to secure the access to land and other resources for smallholders (WFP 2016).

Water management and quality

Water quality was significantly better in certified organic farms enhanced by significantly lower pesticide use and higher information availability with respect to water quality (Tables 3.3 and 3.4). The two counties differed considerably in water withdrawal but not in water quality (Table 3.1). Farms in Kajiado had significantly less information on water availability, used more water for irrigation annually, and did not measure the amount of rainwater water used for irrigation (Tables 3.3 and 3.4).

Agriculture is the largest water user in Kenya, accounting for over 70% of the country's annual water use (FAO 2005). Given that >80% of the country's land mass is located in ASAL regions, which are unsuitable for rainfed agriculture, irrigated agriculture provides an alternative. However, although irrigated agriculture is still minimal in Kenya, with only about 2.4% of the arable land under irrigation, it accounts for > 50% of the water used in agriculture (WRMA 2013). Our results indicate unsustainable water withdrawal in Kajiado. Land conversion in Kajiado from natural ecosystems, wildlife and nomadic pastoralism to cultivation and livestock rearing has increased competition for water resources due to the need for irrigation (Adhiambo et al. 2017). This has been associated with negative environmental, social and economic consequences for the wetlands and livelihoods in the county. For instance, in Kajiado, overutilization of water resources through activities like furrow irrigation led to a reduction in water availability, and water bodies were found to be contaminated with agrochemicals (Githaiga et al. 2003). Similar studies in the county linked irrigation to a reduction in river water quantity and quality over time due to abstraction for irrigation and to pollution (Gichuki and Macharia 2006; Adhiambo et al. 2017).

In Kenya, government-managed irrigation schemes have deteriorated over time due to lack of proper regulation and control over access to water resources (Ngigi

2002). Although there are ongoing efforts to increase the area under irrigation in Kenya and to improve regulations in water management (WRMA 2013), there is a strong need for integrated water resources management (IWRM) including coordination among different sectors, individuals and institutions. This is crucial, as water is not an isolated resource, and other factors such as land-tenure rights also play a role in water management and conservation (Ngigi 2002; Aboniyo et al. 2017). In addition, gaps in knowledge and skills among smallholder farmers in Kenya, which have been identified as a major barrier to their success in agricultural production (Rees et al. 2000b; Ndungu et al. 2013; Mutuku et al. 2017), could explain the poor knowledge level we observed regarding water availability and quality as well as the subsequent overuse. Other factors such as availability of water and water harvesting technologies have been identified as major needs of farmers in Kajiado (Omondi et al. 2014). This implies that there is need for increased awareness on water use, management and storage. Onduru and Du Preez (2008) found similar unsustainability conditions in farms in Embu, another county in Kenya's ASAL regions. According to Mati (2008), capacity development in irrigation schemes for the Kenyan ASAL regions is necessary, and once developed it would has the potential to reduce poverty and food insecurity within approximately three years.

Organic certification

While some studies have reported benefits of organic certification for the livelihoods of smallholders in SSA (Barrett et al. 2001b; Bolwig et al. 2009; Ndungu et al. 2013; Ayuya et al. 2015), there have also been reports of very little or no positive effects. For instance, in Ethiopia (Jena et al. 2012), Nicaragua (Jena et al. 2017) and India (Jena et al. 2018), only a negligible positive impact on the livelihoods of smallholder coffee farmers of organic and Fairtrade certification was found. It is not possible to describe the results of this study in terms of cause-and-effect, and although we observed differences in performance of organic certified compared to non-certified farms, we cannot draw general conclusions about the specific impacts of certification on these farms without a more targeted assessment.

Due to a significantly higher proportion of certified products in the certified compared to non-certified farms and in Murang'a farms compared to farms in Kajiado, sustainability performance was enhanced in many subthemes (Tables 3.3 and 3.4; Appendix B). However, this indicator of share of certified products is based on the implicit assumption that certification has certain positive/negative impacts, and hence this is unsuitable for drawing conclusions about the impact of organic certification.

Furthermore, while organic certification is associated with a greater assurance that farm production practices conform to sustainable practices, our findings show that OA farms in Murang'a and Kajiado are using nearly similar farm and land management practices. The general problem of very low-input systems (organic or non-organic), which are found in most smallholder farms in SSA, is resource depletion in the long term (Adamtey et al., 2016). Additionally, the benefits of organic certification for sustainability may be superimposed by difficulties encountered in the certification process, such as high costs of certification, complex and frequent documentation procedures and heavy bureaucracy involved in the certification process (Barrett et al. 2002; Sahm et al. 2013).

Strategies such as local certification mechanisms, which are cheaper and tap into the growing demand for organic produce, might be a solution to overcome barriers to certification in SSA, (Barrett et al. 2001b, 2002; González and Nigh 2005). Local assurance systems like PGS and certification through contractual arrangements can benefit farmers and offer a more affordable alternative to individual third-party certification (Home et al. 2017; Kaufmann and Vogl 2017). For farmers who are already certified under group schemes, there is a need to strengthen existing local organizational structures, e.g. farmers' cooperatives, as these structures often do not have the administrative and organizational capacities needed for certification, and to raise awareness among the farmers about certification possibilities (Jena et al. 2012).

3.4.4 Limitations

The indicators included in the SMART-Farm Tool are broadly defined to apply to different farm types, settings, climatic conditions and socio-economic contexts in order to have a global applicability. This is important to enable comparability of results(Schader et al. 2014b, 2016). However, the drawback of this all-encompassing approach is that it does not take into account all case- and site-specific factors that may influence sustainability. Moreover, the selection and weighting of indicators based on expert opinion influences the results, and is associated with a certain level of uncertainty (Schader et al. 2016). Moreover, the SMART-Farm Tool rarely measures impacts quantitatively but instead mainly focuses on good practices. Therefore, there is a certain level of uncertainty when conclusions are made, e.g. regarding profitability and farm solvency. Furthermore, there is a potential for auditor bias, since the rating of farms in the different indicators is subjective.

This highlights the need for transparency when working with sustainability assessments (de Olde et al. 2016b) and the complementary use of uncertainty analyses. A corresponding extension of SMART to meet these needs is under development and expected to improve future versions of the tool. Finally, the SMART-Farm Tool is not a universal tool for sustainability assessments, and can be useful to complement other tools and measures but not to substitute them. It is useful for gaining an overview over different areas of sustainability, while other tools such as LCA or RISE can be used for specific areas or applications such as extension services (Schader et al. 2016).

3.5 Conclusions

This study assessed the sustainability performance of smallholder farms in Kajiado and Murang'a counties in Kenya in order to contribute to the ongoing debate on agricultural sustainability and the role of OA in Kenya and beyond. Using the SMART-Farm Tool that operationalizes the SAFA Guidelines of the FAO, as well as MANOVA, other general linear models and effect tests, our results indicate that the main sustainability gaps of smallholder farms sampled are related to lack of reliable information and limited capacity development, limited support for the vulnerable, and limited social security for the farmers and their workers.

Farm comparisons showed no major differences between the five farm types. However, there were modest but key differences, where certified organic farms had an overall higher sustainability performance compared to non-certified farms. This was mainly due to better handling and lower use of synthetic chemical pesticides accompanied by higher soil quality, water quality, biodiversity; higher economic resilience, more long-term investments, sales and income diversification; and better support and training of farm workers, among other factors. However, certified organic farms did not differ significantly compared to non-certified farms in terms of use of mineral fertilizers or organic soil amendments, water use, animal husbandry practices or profitability, and experienced higher yield losses than non-certified farms. Considering the differences between certified and non-certified farms, there is a need for more targeted assessments of the specific impacts of certification on smallholder farms in Kenya.

The results also show modest but significant differences in the sustainability performance of the two Kenyan counties. Apart from Environmental Integrity, farms in Murang'a proved to be more sustainable than in Kajiado in all dimensions. This was mainly due to factors such as better mechanisms to resolve conflicts, better land-tenure security, better customer relationships, more stable profits, and use of practices associated with sustainable farming, . However, Kajiado farms had better linkages to markets with better credit access and animal husbandry practices.

The sustainability of all smallholder farms would benefit from improved capacity development and social protection for farmers and their workers. In particular, non-certified farms would benefit from more diversified livelihoods, long-term farm investments, and more investments in soil and water conservation. Murang'a farmers should ameliorate animal welfare standards and manure management, credit uptake and better linkages to markets, while Kajiado farmers would benefit from more security in land tenure, better irrigation management, investments in the farm business, its customers and employees, as well as cultivation of more perennials and fruit trees. The results of our study offer a starting point for a more comprehensive and all-encompassing discourse on farm-level agricultural sustainability. Development interventions, strategies and policies aiming to improve the sustainability performance of smallholder farms in Kenya, and similar regions in SSA, can begin with addressing the gaps in sustainability highlighted in this study.

4 SOIL FERTILITY AND BIODIVERSITY ON SMALLHOLDER FARMS IN KENYA

4.1 Abstract

The growth of organic agriculture (OA) in sub-Saharan Africa (SSA) raises the question of how far OA can improve the livelihoods of the many smallholder farmers that have to cope with numerous complex biophysical and socioeconomic challenges. Evidence on the impacts of OA in SSA, particularly on soil fertility and biodiversity, still is scarce and inconclusive. The aim of this study was therefore to evaluate and compare soil fertility, decomposition and biodiversity between 20 organic and conventional farms in two counties (Kajiado and Murang'a) in Kenya. Soil sampled at 0-20 cm depth was analysed for physical and chemical properties. The decomposition of crop residues over 3 months was studied using litterbags while pitfall trapping and the derived diversity indices provided insights into arthropod abundance and diversity. Differences in soil properties, mass loss through decomposition, and arthropod abundance were analysed with linear mixed models. Findings show no major differences in soil fertility, decomposition and abundance of arthropods between organic and non-organic farms. However, species richness and diversity on organic farms was significantly higher than on non-organic farms. Overall, farms in Kajiado had higher soil fertility and arthropod diversity than those in Murang'a, while farms in Murang'a had a higher arthropod abundance. It is argued that similar agricultural practices used in organic and non-organic farming systems, irrespective of county and biophysical conditions, strongly influenced soil fertility and biodiversity. Our results demonstrate that OA has the potential to increase arthropod biodiversity, but its ability to enhance soil fertility depends on numerous factors that are likely to undermine OA efforts in this region.

4.2 Introduction

Land degradation (LD), estimated to affect between 1-6 billion ha worldwide(Gibbs and Salmon 2015), is a serious threat to sustainable food production, particularly in sub-Saharan Africa (SSA) where livelihoods are still heavily reliant on agriculture (Salami et al. 2010; Davis et al. 2017). The effects of LD have been severe in SSA with 65% of the total arable land already degraded (Oldeman 1992; Nkonya et al. 2016). Sustainable land management practices are crucial to counterbalance the ongoing land and soil degradation including measures such as mitigation of declining soil fertility, soil erosion, deforestation, biodiversity loss and desertification (Nkonya et al. 2016) that in turn improve land productivity (Zika and Erb 2009). The drivers of LD however differ between countries and even regions within countries due to variable biophysical factors (e.g. rainfall, temperature, longitude, latitude, soil quality), land use, and socio-economic conditions (Maitima et al. 2009; Gibbs and Salmon 2015; Oldeman et al. 2017). This is particularly important in a country such as Kenya characterized by a large variety of agro-ecological zones and diverse - mainly smallholder - farming systems. Since drivers of LD differ, the most effective measures to mitigate them are likely to differ as well.

Kenya is predominantly dry with over 80% of the land classified as arid and semi-arid (ASAL), prone to erratic weather conditions and receiving 150 to 1100 mm of rainfall annually. The remaining land (< 20%) experiences humid to semi-humid conditions with annual rainfall ranging from 600 to 2700 mm. Despite these conditions, rainfed agriculture, mainly practised by smallholder farmers, is the main livelihood source of the majority of the population in Kenya (Sombroek et al. 1982; GoK 2009). However, over 12 million people depend on degraded land, and have to find appropriate means to cope with the on-going degradation of their croplands (Mulinge et al. 2016). This is a major challenge in particular for the rural poor not only due to their high dependency on this natural resource, but also because these resources are virtually their only source of livelihood security (ILO 2016; Nkonya et al. 2016).

Maintaining and improving cropland productivity, which plays a vital role in tackling poverty and food insecurity in Kenya (Murage et al. 2000; De Jager et al. 2001; Giller et al. 2009), is extremely challenging since soil organic matter (SOM) has constantly declined, often because of inadequate use of soil amendments and constant removal of crop residues (Murage et al. 2000). Yet, due to the positive relationship between soil fertility, biodiversity and plant productivity (Delgado-Baquerizo et al. 2017), a stimulus of soil organisms, including macro-, meso- and micro-fauna as well as micro-flora (bacteria, fungi and viruses) can enhance nutrient cycling and modify soil structure (Altieri 1999; Cambardella 2005). Arthropod diversity on cultivated lands has been postulated as a good indicator of the effect of human activity on soil biodiversity, since arthropods in particular are sensitive to environmental changes (Lawes et al. 2005; Hendrickx et al. 2007). Furthermore, given that soil organisms drive litter breakdown, decomposition and cycling of nutrients (Altieri 1999; Gachene and Kimaru 2003; Ouédraogo et al. 2004), soil biodiversity can be rapidly assessed through an examination of ecological activity in soils. Litter decomposition can be used, as it is impacted by a score of factors including the local macro- and micro-climate, composition of decomposing material, chemical and physical soil properties, but also farm management practices (Ouédraogo et al. 2004; Ke et al. 2005; Keane 2008; Kihara et al. 2015).

In an effort to counter the growing LD and accompanying soil infertility, organic agriculture (OA) has been promoted as a sustainable farming approach under the "Ecological Organic Agriculture" (EOA) initiative set up by the African Union in 2011 (Niggli et al. 2016). The initiative adopted a definition of OA similar to that of the International Federation of Organic Agriculture Movements (IFOAM 2013). However, in the literature the sustainability of OA in SSA is disputed. On the one hand, recent evidence from Kenya suggests that smallholder OA farms have increasing agricultural productivity, yields, profitability (Ndungu et al. 2013; Ayuya et al. 2015; Ndukhu et al. 2016; Gyau et al. 2016), soil fertility and quality (Adamtey et al. 2016). On the other hand, challenges associated with OA including reduced nutrient supply, lower yields, increased bureaucracy and process complexity, as well as certification costs, may offset such positive effects of OA (Sahm et al. 2013). An examination of soil fertility and biodiversity in smallholder farms is thus crucial for sustainable land management and conservation efforts. Moreover, previous measures to counter LD and improve biodiversity have been rather general, and rarely account for the often location specific social–ecological context (Nkonya et al. 2016).

While complementing an earlier study (Kamau et al. 2018), the objective of this study was to examine and compare soil fertility and biodiversity on organic and conventional smallholder farms in two biophysically different counties in Kenya by: (i) evaluating soil fertility using key soil physicochemical properties in organic and conventional smallholder farms located in two counties, (ii) assessing the effects of soil micro-/meso-fauna and micro-flora on crop residue decomposition in organically and conventionally managed farms, and (iii) examining the taxa/groups of soil epigeal arthropods, their abundances, richness and diversity in organically and conventionally managed farms.

4.3 Materials and methods

4.3.1 Experimental design

The two study counties were selected through a purposive sampling based on the general presence of certified OA as well as on climatic heterogeneity with the aim of comparing the characteristics of organic and conventional farms. Prior to the field work, a total of 20 farms, i.e. 10 per county, were selected from a total of 488 farms that had participated in a previous study (Kamau et al. 2018). The 20 farms were selected through random spatial sampling using georeferenced data. Each pair of organic and conventional farms was approximately 1 to 2 km apart. In both counties, OA farms represented about 40% of the total sample (Table 4.1).

Table 4.1 Number and share of organic and conventional farms sampled in 2016 in Kajiado and Murang'a counties in Kenya.

Farming system	County		Total	Share (%) of total farms in farming system
	Kajiado	Murang'a		
Organic	4	5	9	44
Conventional	6	5	11	55
Total	10	10	20	

The 10 farms in each county were considered as sampling replication. In each farm with an area ranging from 0.2 to 3 ha, a plot of 0.25 acre (~0.1 ha or ~ 32 m × 32 m or ~ 1011 m^2) within an intercropped field of maize (Zea mays L.) and bean (Phaseolus vulgaris L.) was delineated for soil sampling. The plot was located in the center of the field to avoid border effects. These plots remained marked throughout the experiment, since soil sampling was complemented with pitfall-trapping and litterbag studies.

4.3.2 Data collection

Data was collected in 2015 and 2016. Monthly rainfall and temperature records in 2016 (Figure 4.1) confirmed the two rainfall seasons in both counties with short rains falling between October and December and long rains between March and May. The high rainfall levels in January 2016 were exceptional in Kenya, and can be attributed to the 2015-2016 El Niño events (Kogan and Guo 2017).

Characteristics of agricultural practices of conventional and organic farmers

Data on agricultural practices was collected in 2015 using a semi-structured questionnaire in face-to-face interviews. The questionnaire covered data from two cropping seasons.

Soil sampling and analyses

Soils were sampled at a depth of 0-20 cm in March 2016 immediately following the harvest, but before the soils were ploughed for land preparation. One plot of about 0.1 ha (0.25 acres) was selected on each farm. Each plot (n=20) was divided into 4 equal parts (quadrants) to capture slope, soil texture and other plot-related variability. In each of these 4 quadrants, a zigzag sampling strategy was used to identify 6 locations where the soil was sampled. Subsamples of each of the 4 quadrants were bulked after which a composite subsample (each about 500 g) was taken, thus totalling 4 composite subsamples per plot. In addition, 3 undisturbed cores were collected from each plot at a depth of 10 cm to determine bulk density (BD).

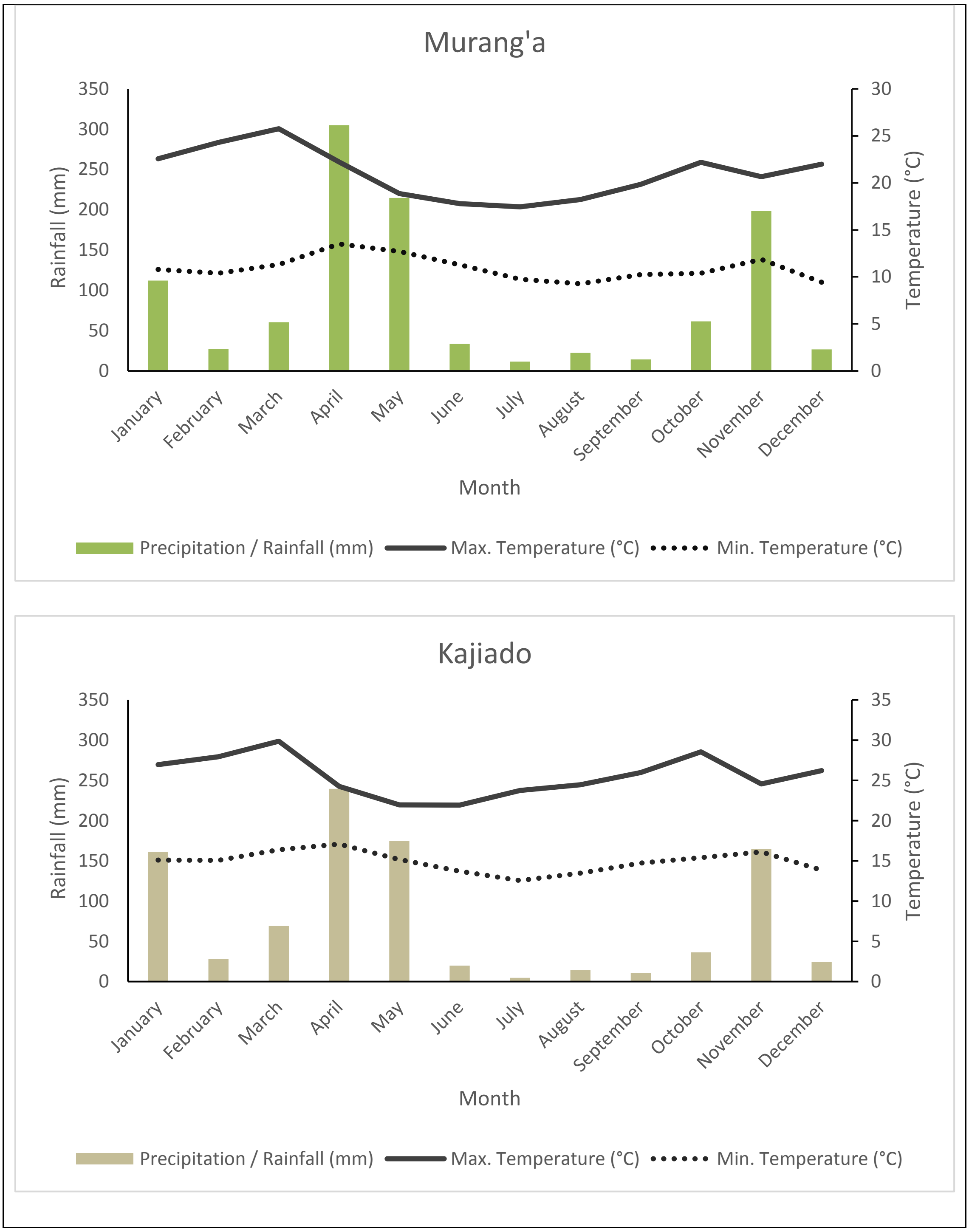

Figure 4.1 Weather for study counties based on 2016 data. Climate Hazards Group (CHG) InfraRed Precipitation with Station (CHIRPS) (Funk et al. 2014) and the NCEP Climate Forecast System Reanalysis datasets (Saha et al. 2013).

Available nutrients including phosphorus (P), potassium (K), sodium (Na), Calcium (Ca), Magnesium (Mg) and Manganese (Mn) were extracted using the Mehlich

Double Acid method (Mehlich 1953). Na, Ca and K were determined with a flame photometer. The concentrations of P, Mg and Mn were assessed spectrophotometrically while extractable P was determined using the Olsen method for soils with pH ≥7.0 (Olsen 1954). Total organic carbon (TOC) was measured through the Calorimetric method while total N was assessed by the Kjeldahl method (Anderson and Ingram 1993).

Trace elements (Fe, Zn, Cu) were determined using atomic absorption spectroscopy. Soil pH was assessed in a 1:1 soil-water suspension with a pH-meter, while electrical conductivity (EC) was determined in a 1:2.5 soil-water suspension using an electric conductivity meter (Hesse 1971; Hinga et al. 1980). Soil texture was measured using the Bouyoucos hydrometer method. The cation exchange capacity (CEC) and exchangeable bases were assessed by leaching the soil with 1N ammonium acetate buffered at pH 7.0. The leachate was analysed for exchangeable Ca, Mg, K and Na. The sample was further leached with 1N KCl, and the leachate used for determination of the CEC. Contents of exchangeable Na and K were analyzed by flame photometry and of Ca and Mg using an atomic absorption spectrophotometer (Hinga et al. 1980; Page et al. 1982; Landon 1984). Bulk density was estimated using the core sampling method on the sampled undisturbed soil cores after oven drying the cores at 105°C for 48 hours (Hinga et al. 1980; Klute 1986).

Litter decomposition

The use of litterbags is recommended to estimate decomposition rates of organic material under field conditions. The litter is enclosed in bags of varying mesh sizes effective in assessing the decomposing activities of fractions of fauna or flora. Depending on the research question, the litterbags are placed above or below ground, collected at different intervals, while the remaining mass at different time intervals is used to estimate decomposition rates (Coleman et al. 2004; Domínguez et al. 2014).

Litterbags with crop residues (30 g maize stover on a dry weight basis, chopped to 1-2 cm) were buried in the plough layer at a depth of about 10 cm at the beginning of the cropping season and just before the onset of the long rains in April 2016 (Figure

4.1; Appendix C1). Fine mesh litterbags of 2 mm nylon mesh were used to exclude most macro-fauna (> 2 mm) but allowed access of meso-fauna (< 2-mm), micro-fauna and micro-flora (<0.1) (Cambardella 2005). Four replicates of litterbags were buried at 4 sampling points in each farm plot (n=20) along a linear transect leading to a sample size of 16 litterbags per farm and a total of 360 litterbags for the two counties. Every month (i.e. from May to July 2016), one out of the four litterbags at each sampling sites was collected, and the dry weight of the crop residues determined after they were washed with water to remove the soil, and oven dried at 105°C for 48 hours.

Pitfall traps

A rapid assessment of arthropod biodiversity using external morphology of different groups/taxa is recommended to evaluate species diversity according to land use (Hackman et al. 2017). Pitfall trapping has been widely used for assessing arthropod diversity, not only because the traps are low-cost and easy to install, but also for their reputation for capturing a large number of invertebrates from a variety of taxa (e.g. Oliver and Beattie, 1993, 1996; Shah et al., 2003; Woodcock, 2005). Five traps were installed on each farm plot (n=20) on the linear transect of 45 m (i.e. each sampling point every 9 m) resulting in a total of 100 traps. The traps were regularly monitored between 14 January and 25 February 2016 (5 weeks), which corresponds to the appropriate sampling time of 10-28 days according to Woodcock (2005). The sampling period coincided with the end of the El Niño event with total rainfall in both counties exceeding 100 mm in January and dropped to <30 mm in February (Figure 4.1).

Each trap consisted of an inner and outer plastic cup sunk into the soil with its rim even with the soil surface. The inner plastic jars (10 cm deep with an opening of 7 cm diameter) contained 150-160 ml of a 1:1 mixture of ethylene glycol and distilled water as a preservative solution. Two drops of unscented detergent reduced surface tension. A hexagon wired mesh (13 cm×13 cm) covered the cup to prevent small mammals and rodents from falling into the poisonous preservative. A metal roof (25 cm×25 cm) was placed 3-4 cm above the ground to prevent the entry of rainwater (Appendix C2). The traps were emptied after 2, 4 and 5 weeks, after which the traps were removed. During each sampling event, trapped arthropods were preserved in 70% ethanol. They were later identified by their external morphology down to order level and, if possible, to lower taxa.

4.3.3 Data analysis

All data was analysed using STATA version 14 (Statacorp, 2015), the SPSS statistical package version 23.0 (SPSS Inc., Chicago, USA) and R version 3.3.1 (R Core Team 2014). Linear mixed-effects models were used to assess significant differences ($p<0.05$) in soil properties, arthropod abundance and decomposition rates with respect to county (Kajiado vs. Murang'a), farming system (organic vs. conventional) and/or time, and their dependency through interactions (e.g. county x farming system x time). The farm was considered a random factor in the model while county, farming system and time were fixed factors. Time was added as a fixed factor to evaluate the dynamics of insect abundance (at 2, 4 and 5 weeks) and changes in mass loss (decomposition) over the 4-, 8- and 12-week period corresponding to the sampling collection at 29, 58 and 87 days after the litterbags had been placed in the field.

To control for any deviations from the assumption of normality, the robust variance estimate option in STATA was used. In cases where factors were identified as statistically significant for a specific aspect, LSD pairwise post hoc tests were performed for means comparison at $p<0.05$. Pearson's correlations were used to analyse possible associations among soil variables. The interpretation of physicochemical soil characteristics was supported by thresholds previously compiled and summarized by Hazelton and Murphy (2007), and the results compared to critical levels of soil fertility reported for the study area (NAAIAP; 2014; Table 4.2).

Table 4.2 Interpretation of soil physicochemical properties using thresholds postulated by Hazelton and Murphy (2007) and critical values for maize growth according to the Kenya national soil report (NAAIAP, 2014).

Soil property	General interpretation						Interpretation for Kenya
	Extremely low	Very low	Low	Moderate	High	Very high	Critical range
TN (%)	-	<0.05	0.05-0.15	0.15-0.25	0.25-0.50	>0.5	≥ 0.2
TOC (%)	<0.4	0.04-0.06	0.06-1.00	1.00-1.80	1.80-3.00	>3.00	≥ 2.7
CEC (me/100 g)	<3	<6	6-12	12-25	25-40	>40	-
Olsen P	-	<5	5-10	10-17	17-25	>25	≥ 30.0
Na (me/100 g)	-	0-0.1	0.1-0.3	0.3-0.7	0.7-2.0	>2	-
K (me/100 g)	-	0-0.2	0.2-0.3	0.3-0.7	0.7-2.0	>2	≥ 0.2
Ca (me/100 g)	-	0-2	2-5	5-10	10-20	>20	≥ 2.0
Mg (me/100 g)	-	0-0.3	0.3-1.0	1-3	3-8	>8	≥ 1.0
pH water	<5.0	5.1-6.0	6.1-6.5	6.6-7.3	7.4-8.4	>8.5	≥ 5.5
BD (g/cm^3)	-	<1.0	1.0-1.3	1.3-1.6	1.6-1.9	>1.9	-
EC (dS/m)	-	<2	2-4	4-8	8-16	>16	-
Mn (me%)	-	-	-	-	-	-	≥ 0.1
Cu (ppm)	-	-	-	-	-	-	≥ 1.0
Fe (ppm)	-	-	-	-	-	-	≥ 10.0
Zn (ppm)	-	-	-	-	-	-	≥ 5.0

The contribution of soil fauna to the loss of crop residue from the litterbags, termed here as litter mass loss, was estimated after each retrieval period. Litter mass loss was expressed as a percentage of remaining dry mass, and calculated according to $D = \frac{M_0 - M_t}{M_0} \times 100$ (Coleman et al. 2004), where M0 is the initial dry mass at time zero, and Mt is the final dry mass at time t. In addition, the rate of breakdown of crop residues for each time period was expressed using the decay constant (k), which was determined as the single negative exponential decay function $M_t = M_0 . e^{-kt}$ (Olson 1963). The model was fitted using a non-linear regression, where k is exponential decay coefficient and t is time in days. Finally, the share of mass remaining at each retrieval period ($M_t/M_0 * 100$) was plotted against time (in weeks), a negative exponential regression curve was fitted to the data, and the intercept forced through 100% at day zero.

Arthropod species richness and diversity was reflected by several indices (i.e. Shannon-Weiner information statistic, Simpson's index and the log-series alpha diversity index computed using the vegan package (Oksanen et al. 2009) and BiodiversityR package (Kindt and Coe 2005) according to Kindt and Coe (2005). Although the above three indices were calculated in this study, only the results of the log-series alpha diversity index or Fisher's alpha diversity index (Fisher et al. 1943) was considered for interpretation. This is because the log-series alpha diversity index has a low sensitivity to sample size, decent discriminant ability, is robust and less influenced by rare or dominant species (Rice and Demarais 1996; Shah et al. 2003) hence it is considered superior to the other two indices (Shah et al. 2003; Magurran 2013). To determine the existence of any significant differences ($p < 0.05$) with respect to farming systems and / or counties, a two-way parametric analysis of variance test (ANOVA) was conducted to compare the values of abundances, richness and selected biodiversity indices with farming systems and counties as main factors and farm as the random factor.

4.4 Results

4.4.1 Practices of conventional and organic farmers

In both regions/counties, organic and conventional farms had little usage of green manure. In the two counties, both organic and conventional farmers hardly used green manure, compost, or off-farm waste, and few recycled crop residues (Table 4.3). Yet nearly all OA farms, and also about 50% of the conventional farms, practised crop rotation. Intercropping, here maize with legumes, and the use of animal manure was equally common in both farm types. Although all farmers used manure, the use of other soil amendments including compost, off-farm waste, mulch and cover crops was more common in OA farms. Notable was that OA farmers kept detailed crop records on crop production and input use and did not use mineral fertilizers or synthetic pesticides in contrast to their conventional counterparts (Table 4.3).

Table 4.3 Summary of farm management practices in organic and conventional farms sampled in Kajiado and Murang'a counties in Kenya, 2016.

	Farming system																			
Farm management practice	Conventional											Organic								
Record keeping													x		x		x	x		x
Legume intercrop	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
Crop rotation	x	x	x				x	x		x		x	x	x		x	x		x	x
Mulch and cover crop	x			x					x			x	x	x	x		x	x		x
Crop residue use					x										x			x		
Animal manure use	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
Green manure use		x	x									x							x	
Use of off-farm waste															x	x				
Compost use			x										x		x					
Synthetic fertilizer use				x	x		x	x	x	x	x									
Bio-pesticide use	x										x	x	x	x	x					x
Synthetic pesticide use	x		x	x	x		x	x	x	x	x									

Note: The main legume used for intercropping is beans (Phaseolus vulgaris L.). *The pattern of crop rotation is irregular and varies widely in time and from one farm to another, but maize*bean intercrop is normally rotated with root tubers, vegetables or other cereals. Cells highlighted in grey show the main practises that differentiate conventional and organic farms.*

4.4.2 Soil properties in relation to farming system and region

Soil properties differed significantly between the two counties for most of the parameters evaluated (Table 4.4). As expected, compared to the soils in Murang'a, the soil in Kajiado (section 2.1) exhibited overall significantly higher levels of BD, sand content, soil macronutrients, available P, base cations, CEC and EC, but significantly lower acidity, Fe and Zn. However, despite the higher levels of macronutrients in soils from in Kajiado, the TOC in both counties was below the critical levels postulated for maize production (NAAIAP 2014). Moreover, total N (TN) was near or below critical levels in Kajiado and Murang'a, respectively (Tables 4.2 and 4.4). There was a significant and strong positive correlation between TOC with TN and with other macronutrients, whilst CEC was negatively correlated with Zn and Fe (Table 4.5).

Due to the small differences between cultivation practices of OA and conventional farmers (Table 4.3), only few soil parameters differed significantly between both farming systems irrespective of the county, also substantiated by the absence of any interactions between county and farming system (Table 4.4). Notable is that the levels of soil macronutrients and pH were relatively higher, though not significantly, in OA farms (Table 4.4). Despite the higher levels of TOC in OA farms compared to conventional farms, both values were below the critical levels recommended for maize cultivation (Table 4.2). In contrast, except for Mg, CEC, EC and BD, the levels of all other soil parameters assessed were above critical levels for maize cultivation and slightly, though insignificantly higher on OA than on conventional farms (Tables 4.2 and 4.4).

Table 4.4 Means of soil physical and chemical properties as affected by farming system and county.

Factor	Farming system			County			Farming system*county				
Variable	Org	Conv	P	Murang'a	Kajiado	p	Org*Murang'a	Org*Kajiado	Conv*Murang'a	Conv*Kajiado	p
pH (water)	6.1a	5.9a	ns	5.5a	6.4b	<0.01	5.6a	6.5a	5.4a	6.4a	ns
TN (%)	0.2a	0.2a	ns	0.2a	0.3b	<0.05	0.2a	0.3a	0.2a	0.2a	ns
TOC (%)	2.5a	2.1a	ns	2a	2.6b	<0.05	2.1a	2.8a	1.8a	2.3a	ns
Olsen P (ppm)	83.5a	58.4a	ns	47.4a	94.5b	<0.05	60.8a	106.2a	34a	82.9a	ns
K (me%)	1.5a	1.2a	ns	1.1a	1.6b	<0.05	1a	2a	1.1a	1.2a	ns
Ca (me%)	13a	12.1a	ns	4.3a	20.8b	<0.001	5.2a	20.8a	3.5a	20.7a	ns
Mg (me%)	3.4a	3.8a	ns	1.6a	5.6b	<0.001	1.9a	5a	1.4a	6.3a	ns
Mn (me%)	0.6a	0.6a	ns	0.6a	0.5a	ns	0.6a	0.6a	0.6a	0.5a	ns
Cu (ppm)	5.1a	5.1a	ns	6a	4.3a	ns	6.2a	4.1a	5.8a	4.5a	ns
Fe (ppm)	63.5a	54.9a	ns	68.2a	50.2b	<0.05	74.4a	52.6a	61.9a	47.8a	ns
Zn (ppm)	29.7a	20.9a	ns	35.4a	15.2b	<0.001	39.4a	20a	31.5a	10.3a	ns
Na (me%)	0.9a	0.7a	ns	0.6a	1b	<0.05	0.6a	1.1a	0.6a	0.9a	ns
EC (mS/cm)	0.1a	0.1a	ns	0.1a	0.2b	<0.05	0.1a	0.2a	0.1a	0.2a	ns
CEC (me%)	31.8a	37.5a	ns	29a	40.3b	<0.05	28a	35.7a	30.1a	44.9a	ns
Sand (%)	12.9a	20.9a	ns	12.6a	21.2b	<0.05	8.8a	17a	16.4a	25.3a	ns
Silt (%)	18.9a	15.6a	ns	16a	18.5a	ns	16.8a	21a	15.2a	16a	ns
Clay (%)	68.2a	63.5a	ns	71.4a	60.3a	ns	74.4a	62a	68.4a	58.7a	ns
BD (g cm-3)	1.1a	1.1a	ns	1a	1.1b	<0.05	1a	1.1a	1a	1.1a	ns

For abbreviations see Table 4.2
*a-b: Different letters within a row indicate significant differences (p<0.05) for columns representing different factors (i.e. farming system, county and farming system*county)*
ns: Not significant (p < 0.05)
1 part per million (ppm) = 1 milligram/kilogram (mg/kg),
dS/m = mmhos/cm = mS/cm
1 CEC cmol/kg = 1 meq/100g, milliequivalents per 100 g soil *(me/100g or* me%*)*

Table 4.5 Pearson product-moment correlation coefficients among soil physicochemical soil properties in Kajiado and Murang'a counties (n=20) in Kenya, 2016.

Soil property	EC	CEC	Sand	Silt	Clay	pH	TN	TOC	P	K	Ca	Mg	Mn	Cu	Fe	Zn	Na	BD
EC	1																	
CEC	0.07	1																
Sand	**.447***	**.487***	1															
Silt	0.192	-0.025	0.443	1														
Clay	-0.396	-0.313	**-.892****	**-.800****	1													
pH	**.847****	0.273	**.581****	0.435	**-.608****	1												
TN	**.606****	0.077	**.497***	**.511***	**-.590****	**.667****	1											
TOC	**.568****	0.073	**.478***	**.522***	**-.583****	**.641****	**.998****	1										
P	**.796****	0.202	0.431	0.363	**-.471***	**.874****	**.650****	**.631****	1									
K	**.673****	-0.169	0.227	0.285	-0.296	**.762****	**.611****	**.587****	**.608****	1								
Ca	**.736****	**.596****	**.564****	0.272	**-.514***	**.813****	**.686****	**.665****	**.750****	**.484***	1							
Mg	0.251	**.796****	0.407	0.07	-0.308	0.442	0.21	0.196	0.328	0.068	**.739****	1						
Mn	0.299	**-.581****	-0.003	0.215	-0.106	0.169	0.025	0.007	0.131	0.314	-0.26	**-.544***	1					
Cu	-0.419	-0.1	-0.276	0.112	0.128	-0.376	-0.25	-0.23	-0.356	-0.426	-0.37	-0.222	0.309	1				
Fe	-0.106	**-.583****	-0.401	-0.425	**.482***	-0.287	-0.433	-0.437	-0.24	-0.036	**-.580****	**-.490***	0.358	-0.012	1			
Zn	-0.026	**-.535***	-0.251	0.016	0.16	-0.112	-0.071	-0.071	0.034	0.104	**-.444***	**-.761****	**.697****	0.373	0.278	1		
Na	**.788****	-0.035	0.317	0.273	-0.349	**.859****	**.620****	**.590****	**.705****	**.965****	**.623****	0.223	0.268	-0.434	-0.125	0.009	1	
BD	0.256	0.362	0.362	-0.046	-0.219	0.25	-0.012	-0.049	0.17	0	0.308	0.402	-0.192	-0.229	-0.038	-0.244	0.1	1

For abbreviations see Table 4.2

** Correlation is significant at 0.05 level. ** Correlation is significant at 0.01 level. Significant correlations are in bold*

4.4.3 Role of soil meso- and micro-fauna and micro-flora in litter decomposition

The rate of crop residue mass loss did not differ significantly, neither between the two counties nor between OA and conventional farms (Figure 4.2). However, irrespective of county and farming system, the dynamics of litter decomposition differed significantly over the 3-month monitoring period (Figure 4.2). The most rapid mass loss occurred in the initial 4 weeks followed by a relatively gradual decline in mass thereafter. After 29 days of decomposition, about 45% residues were left compared to 28% after 58 days, while about 20% remained after 87 days, irrespective of county or farming system Figure 4.3). This was also reflected by the decay coefficients (k) that differed significantly over time, i.e. k1 (after 4 weeks) = 0.20 ± 0.01, k2 (8 weeks) = 0.16 ± 0.01, and k3 (12 weeks) = 0.13± 0.01. This trend mirrored the decreasing rainfall and the temperature pattern in the sampling period from April to end of July 2016 (Figure 4.1).

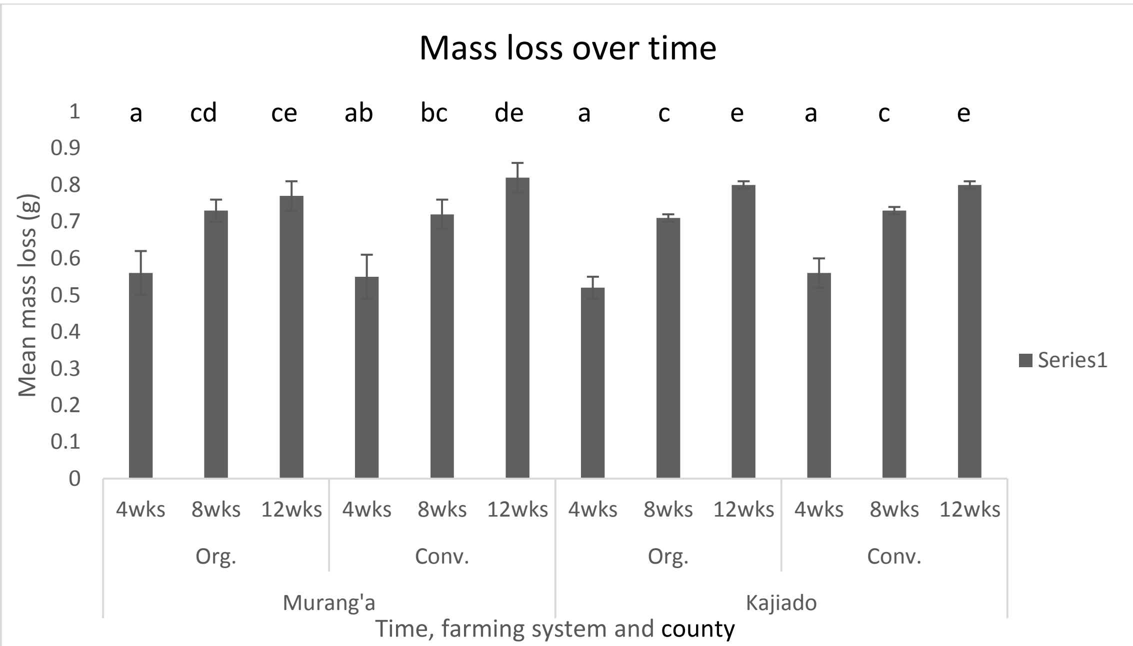

Figure 4.2 Mean mass loss (g) over time (weeks) for two farming systems and two counties. Vertical bars indicate standard error (SE) of mean. Different letters indicate significant differences between species at $p < 0.05$.

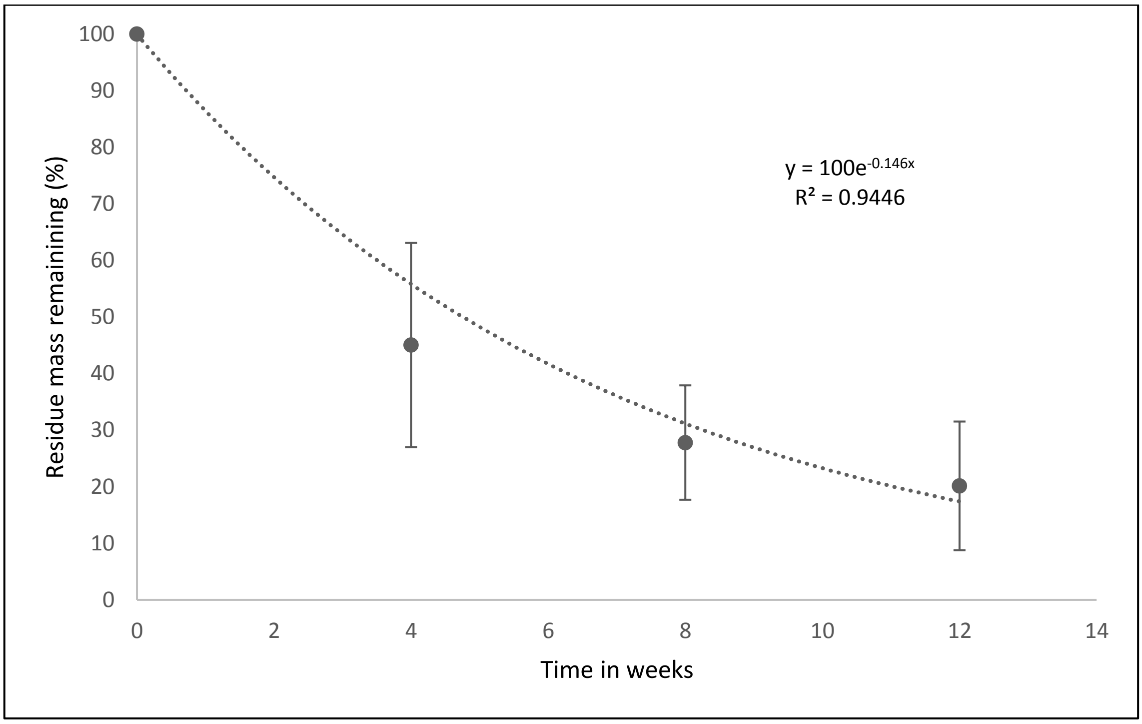

Figure 4.3 Residue decomposition over time in Kajiado and Murang'a counties for organic and conventional farms. Vertical bars represent standard error of mean (multiplied by 10 to improve visibility).

4.4.4 Arthropod diversity in relation to farming systems and counties

During the three-months sampling period, 36,397 arthropod individuals from 18 orders were identified (Table 4.6). Overall, Hymenoptera were the most abundant group counting for over half (56%) of all individuals trapped, followed by Orthoptera (15%), Isoptera (10%) Araneae (4%), Collembola (4%), Diptera (3%), Coleoptera (3%), Trombidiformes (3%), Hemiptera (1%) and Isopoda (1%). The remaining orders constituted less than 1% of the arthropods recorded (Table 4.6).

Higher-level interactions of arthropod abundance existed between time of sampling, farming system and county: it did not differ significantly, neither between OA and conventional farms nor between the three sampling periods, but between the two counties (Figure 4.4). During the sampling period, significantly higher numbers of individuals were captured in Murang'a (abundance = 23200), than those in Kajiado (abundance =13197), (Figure 4.4; Tables 4.6 and 4.7). Arthropod diversity was significantly higher on farms in Kajiado compared to those in Murang'a. Additionally, the log-series alpha diversity index (ἀ) was significantly higher on organic farms (ἀ =1.9) than on conventional farms (ἀ =1.7). Overall, significantly more orders of arthropods were monitored on OA farms (richness=17) compared to conventional farms (richness =16) irrespective of county (Tables 4.6 and 4.7).

Table 4.6 Share (%) of individuals of each taxa/groups of soil-epigeal arthropod order in relation to the total catch according to county and farming system, January and February 2016.

			Region		Farming system	
Order	% of total	Total	Murang'a	Kajiado	Organic	Conventional
Araneae	4	1629	899	730	755	874
Hymenoptera	56	20353	15586	4767	9318	11035
Orthoptera	15	5401	2829	2572	2716	2685
Isoptera	10	3540	1010	2530	1004	2536
Collembola	4	1566	863	703	960	606
Diptera	3	1220	754	466	778	442
Coleoptera	3	1094	490	604	521	573
Trombidiformes	3	1020	607	413	446	574
Hemiptera	1	293	113	180	151	142
Isopoda	1	192	9	183	111	81
Blattodea	<1	24	8	16	10	14
Protura	<1	19	10	9	12	7
Polyxenida	<1	15	14	1	9	6
Pseudoscorpiones	<1	10	3	7	8	2
Lepidoptera	<1	9	5	4	7	2
Thysanoptera	<1	6	0	6	6	0
Dermaptera	<1	3	0	3	0	3
Neuroptera	<1	3	0	3	3	0
Total individuals		36397	23200	13197	16815	19582
Richness		18	15	18	17	16

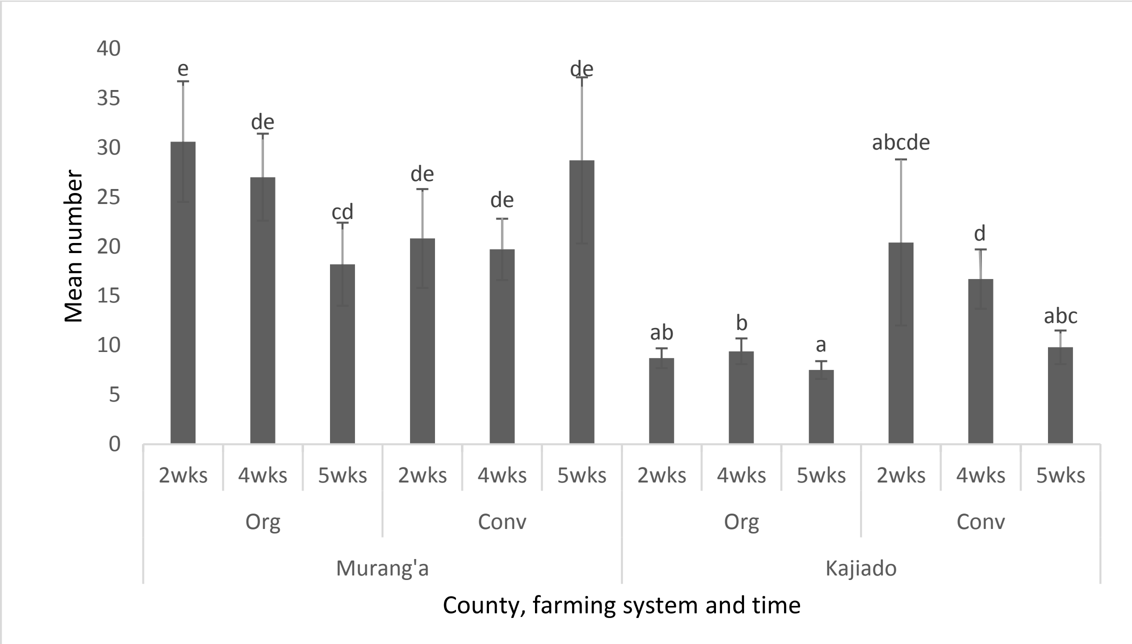

Figure 4.4 Mean arthropod count for two farming systems, two counties and over a 5-week period. Vertical bars indicate standard error (SE) of mean. Different letters indicate significant differences between species at $p < 0.05$ based on LSD.

In summary, results reveal that major differences between the two counties were related to soil fertility, and abundance and diversity of arthropods, but not to the rate of crop residue decomposition. Kajiado farms had more fertile soils and greater arthropod diversity than farms in Murang'a, although the latter had a greater abundance of arthropods. Differences in soil fertility and rate of residue decomposition due to the farming practices were marginal, despite the overall greater diversity and richness of arthropods in organic farms. The effect of time was only important in explaining residue decomposition rates (Table 4.8).

Table 4.7 Diversity indices in relation to farming system and county.

	Farming system		ANOVA		County		ANOVA[1]	
	Conventional	Organic	Farming system F_{1-16}	P>F	Kajiado	Murang'a	County F_{1-16}	P>F
Shannon	1.5	1.5	1.3	0.2745	1.8	1.2	11.1	0.0042**
Simpson	0.6	0.7	0.7	0.4066	0.8	0.5	8.7	0.0094**
inverseSimpson	2.8	2.9	2.1	0.1644	4.6	2.1	9.6	0.0069**
Logalpha	1.7	1.9	5.1	0.0378*	2.1	1.6	12.4	0.0028**
Richness	16	17	5.2	0.0364*	18	15	2.8	0.1148
Abundance	19582	16815	0.1	0.8176	13197	23200	7.1	0.0170*

*1 Two-way ANOVA with farming system and county as main factors and farm as random factor *** p<0.001, **p<0.01, *P< 0.05*

Table 4.8 Overview of overall sources of variation between farms with respect to county, farming system and time of sampling.

	Factor			Interaction	
Assessment	Region	FS	Time	County*FS	County* FS*Time
1. Soil properties	p < 0.05	ns	n/a	ns	n/a
2. Litterbag residue decomposition	ns	ns	p < 0.01	ns	p < 0.01
3. Pitfall trapping					
i. Abundance	p < 0.01	ns	ns	ns	p<0.05
ii. Richness	ns	p < 0.0	n/a	ns	n/a
iii. Diversity (ά)	p < 0.01	p < 0.05	n/a	ns	n/a

Note: ns= not significant, n/a= not applicable

4.5 Discussion

4.5.1 Soil fertility status in relation to farming system and county

Major differences in soil physicochemical properties between the two counties did not depend on farming practices. This confirms previous findings in other parts of Kenya (De Jager et al. 2001; Tittonell et al. 2005a). For instance, the differences between soil nutrient flows and balances between low external input, OA and conventional farming systems were not statistically significant in eastern Kenya for a number of years (De Jager et al. 2001). The authors pointed in particular to the role of historical activities, because a positive nutrient balance can be expected only if the initial system has exhibited reduced nutrient losses, e.g. through leaching and volatilization. An absence of consistent differences in soil physicochemical properties between OA and conventionally managed farms was also reported in Austria and Iceland (van Leeuwen et al. 2015) and the Netherlands, where in particular soil type turned out to be a key factor influencing soil properties rather than management per se (van Diepeningen et al. 2006).

Nonetheless, the level of macronutrients in the soils of the OA farms in this study was statistically not lower than that of conventionally managed farms, and even had a general tendency to be higher, which might in part reflect the increased levels of soil amendments applied on OA farms. Based on a long-term study in Kenya, high-input organic systems could increase the accumulation of N and K compared to high-input conventional systems (Adamtey et al. 2016). However, although OA has previously been accredited for improved soil fertility as substantiated by reported increases in TN, P, SOM, TOC, and CEC levels and also improved soil structure (Bulluck et al. 2002; Rasul and Thapa 2004; Marinari et al. 2006), both high-input conventional as well as low-input organic and conventional systems can deplete macronutrients (Adamtey et al. 2016).

Previous evidence indicated that continuous low-input maize management decreased soil macronutrients, pH and EC in western Kenya (Moebius-Clune et al. 2011), while a continuous cropping with low inputs and poor erosion control in Murang'a has been blamed for marked decreases in TOC, pH, and N levels on smallholder farms (Ovuka 2000a). On the other hand, an increase in SOM is considered a long-term process, particularly in semi-arid environments characterized by increased SOM turnover rates. Consequently, Sanchez et al. (2004) postulated that under semi-arid agro-ecological conditions, an increase in SOM is mainly proportional to the annual amount of organic matter added irrespective of whether or not mulch is applied or residues are incorporated. This seems to be supported by the finding in this study where decomposition rates of the maize residues resulted in only 20% biomass remaining after 3 months. Hence, assessing the long-term impact of soil amendments on SOM usually necessitates long-term experimental data (Ding et al. 2002).

Although it is a challenge to ascertain if differences in soils arise from inherent properties, previous management or both, the variation of clay and sand content between the two counties suggests that inherent soil properties were largely responsible for these differences (Murage et al. 2000). This can be explained by the fact that the soils in both counties originated from different parent material. In addition, the values fell within ranges previously reported for Kenya (NAAIAP 2014), and seemed to be hardly impacted by farm management practices. The soils on farms in Murang'a were in general less fertile than those of Kajiado due to their high acidity and deficiencies in TN and TOC as well as lower available P, even though soils in Kajiado were also limited in TOC. More alarming, however, is the fact that the levels TOC were critically low in both counties, which implies low SOM contents. This in turn is more crucial for Murang'a due to concurrent deficiency in TN. In Kajiado, soil salinity was likely to be another limiting factor for plant growth and microbial activity (Gachene and Kimaru 2003; Hazelton and Murphy 2007; Takoutsing et al. 2016).

The higher levels of base cations and CEC in Kajiado soils compared to those of Murang'a were not surprising, since high-rainfall areas like Murang'a are much more prone to leaching and erosion resulting in a loss of base cations unlike drier areas like Kajiado (Gachene and Kimaru 2003; McKenzie et al. 2004). Whereas the leaching of base cations reduces the levels of CEC and pH in the soil, CEC and pH are also affected by the amount and kind of clay and the SOM content. Since the clay content did not differ significantly between the counties, the detected variations in CEC and pH can therefore be attributed to the SOM content, which plays an important role in enhancing CEC through the adsorption of cations (Murage et al. 2000; Gachene and Kimaru 2003), and could be influenced by farm management practices (Takoutsing et al. 2016).

In smallholder farms in Kenya, practices such as continued cropping, removal of crop residue and insufficient use of soil amendments, which deplete SOM, have been blamed for driving soil degradation resulting in low productivity and large yield gaps (Mairura et al. 2007; Mutegi 2012). Such practices reduce macronutrient levels and also CEC through the reduction of base cations, which consequently decreases soil fertility (Murage et al. 2000; Takoutsing et al. 2016). Our findings also show that soils in Murang'a had higher Fe and Zn contents, very likely because acidic soils are associated with Fe and Zn toxicities, and Ca, Mg and K deficiency (Kisinyo et al. 2013).

In summary, the results underline the importance of including remedial measures to decrease soil acidity and increase the low cation exchange in Murang'a, with the final aim of increasing SOM, which will help to reduce N losses. For acid soils, which are very common in high-rainfall areas in Kenya, cultivation practices could include liming together with addition of P-fertilizers although the amounts added should be tailored to specific crop and field requirements even within the highlands (Kisinyo et al. 2013). Inherent soil properties and soil-forming factors played an important role in explaining the quantities of assessed soil properties such as pH, CEC, base cations, P, K and TN. In addition, previous management practices were important in explaining variability in soil properties such as the low levels of SOM in both counties as represented by critically low levels of TOC, which decreases nutrient availability and affects soil structure and also exacerbates other problems like erosion. Therefore, our findings stress the need to change some of the unsustainable farming practices such as the limited use of soil amendments, the removal of crop residue and continuous cropping that undermine soil fertility, reduce soil productivity, and decrease yields, thus contributing to food insecurity and poverty (Moebius-Clune et al. 2011). Together with previous findings from Kenya, the results indicate that OA practices did not reduce soil fertility, but rather have the potential to improve it when accompanied by suitable management practices.

Nevertheless, the uptake of sustainable farming practices is constrained by numerous socio-economic constraints faced by smallholder farms such as level of wealth . For instance, Tittonell et al. (2010) reported soil nutrient stocks (C, P, K and N) as being more than twice as high in wealthier smallholder farms in East Africa than in poorer ones. Low-input, subsistence-oriented farming systems in Kenya were found to lead to high levels of nutrient mining, particularly of N (De Jager et al. 2001). Other factors such as effective markets and extension services have been mentioned to increase adoption of sustainable and resource-conserving agricultural practices (Munthali et al. 2012). However, the present national budget constraints in Kenya and other SSA countries prevent the setting up of effective structures, and are often dedicated to input subsidies rather than to the development of rural infrastructure, markets, research and extension services (Nkonya et al. 2016). Hence, effective mitigation measures among smallholders can include strategies to enhance access to all forms of productive assets and increased government investment in rural infrastructure.

4.5.2 Soil organisms and crop residue decomposition

The rapid initial decomposition of crop residue in litterbags, with around 72% of the maize stover disappearing within 58 days, is in line with rates previously reported for other parts of SSA (e.g. Kihara et al. 2015, Murungu et al. 2011). Since decomposition is affected by various factors including climate, soil properties, litter quality (i.e. percentage C, N, lignin, polyphenols and C:N ratio), and farm management, addressing one factor in isolation is insufficient for explaining empirical decomposition rates (Keane 2008; Zhang et al. 2008). The insignificant effect of differences in biophysical conditions and farm management represented by the two counties and farming systems implies that other factors not considered in the assessment were also important in influencing decomposition. In contrast to the results of this study, management practices in different farming systems (e.g. conventional, conservation tillage, integrated, fallow management) considerably affected the density and activity of soil fauna in Germany (Ke et al. 2005). Similarly, litter decomposition was higher in OA farms compared to conventional farms in Argentina (Domínguez et al. 2014) and in Burkina Faso on farms managed without pesticides than on those using pesticides (Ouédraogo et al. 2004). In addition, higher density and diversity of soil flora such as fungi, bacteria and nematodes were reported for OA farms compared to conventional farms (Yeates et al. 1997; Tu et al. 2006; van Leeuwen et al. 2015; Khalil et al. 2016).

4.5.3 Arthropod abundance, richness and diversity

The monitored dominance of Hymenoptera taxa resembles earlier findings by Ayuke et al. (2009) in Embu, Kenya, where Isoptera, Coleoptera, Orthoptera and Araneae were the dominant groups after Hymenoptera. Overall abundance of the different arthropod taxa differed only between the two counties but not between farming systems, implying that the abundance was affected more by biophysical differences than by agricultural practices. On the one hand, this is in line with previous studies (e.g. Ayuke et al. 2009) in Kenya reporting little effect of farm management practices on the abundance of macro-fauna, but on the other hand is in contrast to other studies showing significantly higher abundance of mites (Trombidiformes) in organic fields compared to conventional fields in Egypt (Khalil et al. 2016) or of beetles (Coleoptera) in England (Shah et al. 2003).

Although the influence of agricultural practices was not directly linked to arthropod abundance, there was a clear tendency that richness and diversity was significantly higher on OA farms compared to conventional farms. This confirms the findings of other studies, for example in South Africa (Gaigher and Samways 2010) and Europe (Maeder et al. 2002; van Diepeningen et al. 2006; Marinari et al. 2006; van Leeuwen et al. 2015). A 30-year meta-analysis, although mainly considering data from Europe and North America, concluded that OA practices increased species richness by approximately 30% (Tuck et al. 2014). This is in stark contrast to the observed negative effects of conventional farming on soil fauna (Ke et al. 2005; Domínguez et al. 2014).

In general, the farms in Murang'a had a higher abundance of arthropods while farms in Kajiado had a higher diversity, once more indicating the crucial role of biophysical factors. The abundance of different arthropod taxa in some regions compared to others is often linked to differing climatic conditions. For instance, in several eastern and western African countries, long-term diversity trials showed an abundance of earthworms in regions with higher altitudes, higher rainfall and lower temperatures, while termites for example were more dominant in warmer and drier regions, since such conditions favor termites (Ayuke et al. 2011). Despite the short duration of this study, our findings correspond with those of long-term experiments (Glaser 2006; Smith et al. 2014; Nowrouzi et al. 2016), with more individuals belonging to the Isoptera order (mainly termites, data not shown) found under the ASAL conditions of Kajiado and higher abundance of ants in high-altitude areas (76% of collected Hymenoptera in Murang'a were ants, data not shown).

4.5.4 Overarching role of farm practices

This study findings together with previous results (e.g. Ayuke et al., 2009; Kihara et al. 2015; Maeder et al., 2002) reinforce the positive relationship between soil biodiversity and fertility as seen in Kajiado and for the OA farms, which may positively impact yields due to increases in crop productivity (Delgado-Baquerizo et al. 2017). Farm management practices that enhance both soil fertility as well as biodiversity therefore can play a major role in improving the livelihoods of smallholders in Kenya and beyond. Although no distinction was made in this study between low-input versus high-input farms, neither organically nor conventionally managed, an adequate use of inputs for soil improvement is a prerequisite regardless of farming system (Adamtey et al. 2016). This therefore has implications not only for Kenya, but also for other SSA countries where soil mining is prevalent.

Numerous recommendations for farm management practices have the potential to counterbalance the poor and declining soil fertility prevalent in SSA. These vary from intercropping systems (e.g. cereals with legumes) and the promotion of biological N fixation to the use of adequate amounts of soil amendments, erosion prevention, and other control measures such as terracing when cultivating steep slopes (Ovuka 2000a; De Jager et al. 2001). Obviously, building SOM content has recurrently been underlined as a priority, as it influences the structure and texture of soil, reduces nutrient leaching, increases water holding capacity, supports microorganism activity and increases overall soil health and fertility (Rasul and Thapa 2003b). However, in the study counties in Kenya this remains challenging due to the high turnover rates of organic materials such as crop residues.

Therefore, it can be crucial to concurrently promote materials with slower decomposition rates such as wood shavings, sawdust and black carbon to stabilize decomposition over time (Bationo et al. 2011). Additionally, since the composition of decomposing material is important in determining the amount of nutrients released for plant uptake, soil amendments of high quality, for example with lower C:N ratios, are preferable. Crops such as *Tithonia diversifolia* Hemsley A. Gray (Asteraceae), *Calliandra calothyrsus* Meissner (Fabaceae), *Leucaena leucocephala* (Lam.) de Wit (Fabaceae), *Croton megalocarpus* Hutch (Euphorbiaceae), and *Lantana camara* L. (Verbenaceae) are high-quality organic sources of nutrients such as N and P, which are usually deficient in soils of Kenya and beyond (Sanchez 2002; Kwabiah et al. 2003; Bationo et al. 2011).

The recommendations for building SOM by leaving land fallow for a given time period is a challenge for smallholder farmers in Kenya, since the majority of the farms are gradually becoming smaller in size due to land fragmentation (Ovuka 2000a). As a consequence, most smallholders cannot afford leaving land fallow for the time the soil needs to naturally regain nutrient balance. In addition, the majority of these farmers are poor, resource constrained, and have to make trade-offs in the use of resources between competing needs like the use of crop residue as livestock fodder or fuel or recycling it on their farms. Moreover, manure might be limited as it depends also on the number of animals reared (Gachene and Kimaru 2003). Nonetheless, short- and long-term management options that aim at improving soil fertility and biodiversity on smallholder farms need to include adequate use of organic matter in soils to enhance nutrient availability and retention, improve CEC, stabilize pH, increase activity of soil organisms and decrease the likelihood of erosion (Moebius-Clune et al. 2011; Mathew et al. 2016).

This study had several limitations including a relatively small sample of only 20 farms and the short period of sampling. In addition, although the effects of OA in improving soil fertility are observed over time depending on the initial state of the farm, this cross-sectional study reflects the situation at the time it was conducted, and more long-term studies with larger samples can give more generalizable results. However, the study increased the understanding on the role OA can play in mitigation efforts to counter land degradation in smallholder farms in Kenya.

4.6 Summary and conclusions

Soil fertility and biodiversity were compared between organic and conventional farm management practices while taking into account the different biophysical factors represented by two different counties in Kenya. Soil fertility differed between the two counties, but not between organic and conventional farms. Decomposition did not differ between the two farming systems or between the two counties. Organic farms, however, had a higher arthropod richness and diversity of arthropod groups compared to conventional farms.

The findings underline a strong, positive link between soil biodiversity and fertility, and their potential in sustaining crop productivity. Although innate biophysical conditions played a key role in explaining differences in soil fertility and biodiversity, the role of management practices was crucial, irrespective of biophysical differences. Therefore, to improve soil fertility and biodiversity, and in turn crop productivity, there is a need to consider both farm management practices and biophysical conditions, which vary widely in Kenya, by adopting region- and site-specific measures.

Farming systems like OA have the reputation to enhance soil fertility and biodiversity, which was only partly confirmed in this study. Some of the findings, however, can be explained by the fact that differences in farm management practices between OA and conventional smallholder farms in Kenya - and other parts of SAA - are not as strong as they are elsewhere, e.g. in Europe or the USA. The practicability of OA practices is known to depend on numerous factors including social-economic, political and even cultural factors, which could not be considered in this study, but that reportedly affect smallholder farmers. Such factors may obstruct all pathways to arrest the ongoing soil-depleting systems in Kenya. Therefore, while it is important to continue supporting OA as a rapidly expanding niche in Kenya and SSA, an enabling macroeconomic environment with improved rural services such as better access to inputs, markets and extension services may enhance the adoption of sustainable soil management (Kirui and Mirzabaev 2014; Nkonya et al. 2016).

5 SYNTHESIS

5.1 Contribution of typology construction and analysis of sustainability of smallholder farms to sustainable agriculture

This research contributes to the knowledge base on smallholder farming and sustainable development different ways. First, the farm typology identifies unique strengths, constraints and opportunities to improve sustainability, which are type and context specific, and therefore provides a basis for the systematic development of targeted of interventions. Secondly, by assessing sustainability of smallholder farms using a comprehensive set of indicators, the concept of sustainable development is made practical at farm level. The results provide an overview for opportunities from where interventions can embark on, to tackle specific sustainability gaps and carry out more targeted assessments.

Moreover, the assessments provide a learning opportunity, raise awareness on challenges to sustainability at farm level, and form a basis for the discourse of sustainable development in Kenya. Furthermore, since the assessments in this study are based on the SAFA Guidelines, that are globally applicable, the results can be compared with others worldwide. The consideration and combination of both diversity and biophysical characteristics in smallholder farms is a novelty in the study region and Kenya in general. This research contributes to closing the gap in knowledge on the role of OA and organic certification, as well as the role of soil fertility and biodiversity in comparisons of organic versus non-organic smallholder farms. Although these are one-time evaluations that give a snapshot of the farms' situation at the time of the study, the findings can give an indication of how OA is fairing as efforts to promote it and legislate it continue in Kenya and beyond.

5.2 Implications and recommendations

In the long term, development involves a transition from reliance on agriculture to non-agricultural-based livelihood strategies, and SSA is not on a different course (Foley et al. 2005; Davis et al. 2017). Nevertheless, livelihoods in the region are still heavily reliant on agriculture. Therefore, sustainable development in SSA requires a focus on rural structures and smallholders (Salami et al. 2010; von Braun 2010; Dethier and Effenberger 2012). Complex and connected challenges such as changing demographics, land degradation, land use and climate change, however, require holistic approaches that simultaneously address the social, economic and ecological aspects of sustainability. This research has identified several areas on which efforts seeking to promote sustainability SSA can focus. They are mainly based on building the total stock of physical, financial, human, social and natural capital (Serageldin et al. 1994; Pretty 1999).

5.2.1 Physical and financial capital

The need to build physical and financial capital through improved access to productive assets e.g. land, income, quality inputs, mechanization and infrastructure, for pro-poor growth and reduction of inequality Kenya and beyond is repeatedly emphasized in this research (Chapter 2-3) and in literature (Radwan 1995; Dethier and Effenberger 2012; Njeru and Gichimu 2014; Ayuya et al. 2015). Some key efforts to improve sustainability of smallholder farmers identified in this study are:

a) Land tenure rights need to be strengthened: Land is a critical resource for agricultural growth (Radwan, 1995). Constraints such as insecure tenure, unequal access to land, and lack of proper transfer mechanisms are associated with land degradation, limited farm investments, food insecurity, gender inequality, and conflicts (Campbell et al. 2000; Salami et al. 2010; Oluoko-Odingo 2011). Therefore, poverty reduction policies and efforts need to enhance land ownership rights especially in ASAL areas like Kajiado where land rights are rather insecure. This in turn might motivate farmers to make more long-term investments in the land. Furthermore, there is a need to remove barriers that restrict access to land by disadvantaged groups like women, the poor and the youth, which can reduce inequality and enhance their ability to accumulate wealth.

b) Diversification among smallholder farmers should be promoted: Income and livelihood diversification (non-/off-farm and farm activities) was found to be beneficial to smallholders in this research and other studies in SSA countries (Davis et al. 2017; Kamau et al. 2018). Income diversification has been found to be associated with greater wealth than over-reliance on farm income. Furthermore, it creates resilience as it enables rural families to manage risks, and thereby reduces their vulnerability to environmental and economic shocks. Additional income from non-/off-farm work is also important for accessing additional land, or acquiring land for those lacking initial landholding as well as the possibility of moving into other activities like processing. This underlines the importance of diversification for smallholders thereby increasing their resilience.

c) Access of smallholder farmers to credit should be enhanced: Access to agricultural financing is vital for pro-poor growth (Place 2009; Njenga et al. 2011). Since agriculture needs intensive investments, access to credit, which was found to limited in this research (Chapter 2-3) should be enhanced. Loan products need to be sound to finance agriculture, to improve lenders' ability to recover their investments and encourage borrowers, particularly the risk averse, to access credit. For instance, since agricultural income is seasonal, short-term, high-interest loans paid in monthly installments may not be appropriate, hence quarterly or bi-annual repayment plans may be more appropriate, especially since farming may take a few years to break even. However, profit maximizing financial institutions may not be able to provide such products without an enabling policy environment.

d) The development and application of technological innovations should be supported: Technological growth plays a crucial role in sustainable resource use and fighting food insecurity (von Braun 2010; von Braun et al. 2017). In Kenya and other SSA countries, where farming is still basic and uses pre-agrarian revolution methods with limited or no mechanization or input use, is dependent on seasonal rainfall, shows low productivity with large yield gaps, and is subsistence orientated, technological innovations can play a key role for the sustainable transformation of agriculture. High-impact technologies that are promoted as having the ability to boost agricultural productivity include bio-fortification, biotechnology and nanotechnology (von Braun, 2010). Other innovations such as micro-irrigation, precision agriculture and the use of information and communication technology (ICT) networks can enhance sustainable resource use. Kenya has the advantage of having a well-developed ICT sector which can offer vital services to farmers. This research particularly highlighted the need for irrigation water management as well as yield loss reduction (Chapter 3) where innovations like drip irrigation and post-harvest technologies could largely boost productivity. However, for innovation to be successful there is a need for an enabling policy environment as well as public and private investment and cooperation. In addition, research on context specific innovations and their sustainability implications is needed.

e) Information access for farmers on the whole agricultural value chain such as input use, proper record keeping, market opportunities and weather forecasts needs to be improved: Information access enhances technological adoption (Chapter 2-3) but its acquisition and utilization are often influenced by illiteracy, affordability, linkages with external support to farmers as well geographical location (Maumbe 2010; Thuo et al. 2014).

5.2.2 Human and social capital

Human and social capital, which helps to build the asset base (Pretty 1999), has been identified by this research and other studies in SSA as an aspect to be improved. Human capital involves investment in people in terms of education, skills, knowledge and health while social capital is broader and involves inclusion and participation of people in societies (Serageldin et al. 1994; Pretty 1999). The well-documented gap in education, knowledge and skills of smallholder farmers in SSA (Rees et al. 2000b; Marenya and Barrett 2007; van de Steeg et al. 2010; Kamau et al. 2018) affects the well-being of farmers and farm productivity (Marenya and Barrett 2007) and compromises farms' success as business enterprises (Muriithi et al. 2014).

This knowledge and skills gap is largely responsible for the high share of informal labor in Kenya, where over 50% of the labor force is informal and comprises mostly women and the youth (i.e. below 35 years) (Barrientos et al. 2002; Dolan 2004; Keizi 2006; Hope 2011). This research and other studies indicate that smallholder farms are largely owned by older farmers, mainly male and with limited education beyond high school (Chapter 2). Besides, although the majority of the younger generation in Kenya has a basic education, young people lack post-school technical or vocational as well as professional training. Their plight is exacerbated by the upgrading of many tertiary institutions and mid-level colleges in Kenya to universities, where a gap has been left in vocational training (Njenga et al. 2011; ILO 2016). Since growth driven by employment is important for poverty reduction (Radwan 1995), there is a need to close this gap and provide jobs particularly for the youthful Kenyan population (Filmer and Fox 2014). Education and training is necessary to develop and build skills and competencies. Agriculture and manufacturing have the potential to fill the void in unemployment in Kenya and beyond in the short term. With the right skills, the youth can be involved particularly in activities higher in the agricultural value chain such as processing and marketing of agricultural produce as well as in the supporting service sectors and other non-agricultural sectors.

Kenya and other countries in SSA can emulate developments in other countries like Germany, which promotes skills development through the 'Duale Ausbildung', a dual vocational training program that combines practical and theoretical knowledge and skills through apprenticeships in collaboration with the private sector (Ryan et al. 2011). This shows the importance of public private partnerships (PPP), as Ryan et al. (2011) found that incentives for the employer can influence their commitment to invest in the skills of their employees.

Different social groups, e.g. women, youth, the poor, indigenous groups and the elderly, have different needs and capabilities in social learning (Shaw and Kristjanson 2014). Particular social networks need to be strengthened, which can also contribute to participatory learning that in turn is associated with breaking market barriers, promoting access of inputs and credit at group level and other benefits (Fischer and Qaim, 2014, Riisgard Okinda, 2018). However, despite their reported success, entry to these groups is not always inclusive, particularly for the poor who may need to make financial contributions (Chapter 2). In addition, their formation is sometimes based on hierarchical top-down approaches that fail to take into account local and farmer knowledge and skills in decision-making, hence voluntary horizontal approaches are preferred to encourage participation (Serageldin et al. 1994; Snyder and Cullen 2014; Jena et al. 2017). Therefore, there is a need to address the barriers for the entry to these groups as well as to involve participation of members at every level of decision-making.

This research also highlights the need to support vulnerable groups and enhance the social security of smallholder farming (Chapter 3). This support is lacking mainly due to the informality of labor in rural areas, which is characterized by low wages and lack of essential employment rights such as paid leave and support for the disabled (Barrientos et al. 2002; Dolan 2004; Keizi 2006; Hope 2011). There are national safety net programs in Kenya that target the poor and vulnerable people like those having severe disabilities, older persons, and children (World Bank 2013, 2017). However, despite the existence of a cohesive social protection policy in the country, poor institutional coordination and management and limited awareness among workers are the main reasons that hinder their success (Mathauer et al. 2008; ILO 2016), hence stronger linkages between institutions involved in social protection and empowering of workers have the potential to improve this situation.

5.2.3 Natural capital

To improve sustainability in smallholder agriculture, there is a need for better use of available natural resources (i.e. natural capital like soil, water and biodiversity) (Pretty 1999). The issue of poor farm management practices and their effect on soil fertility, biodiversity and crop productivity in smallholder farms is recurrent in this research (Chapters 2, 3 and 4) like in other studies in SSA (Ovuka 2000a; De Jager et al. 2001; Moebius-Clune et al. 2011; Kihara et al. 2015). The research findings show that smallholder farms are largely failing in managing these natural resources in a sustainable way as evidenced by factors such as poor animal husbandry practices in Murang'a, and soil depleting activities, and poor water management in Kajiado (Chapter 3-4).

There is a consensus in literature that farming in SSA needs to intensify to promote sustainable agricultural growth (Snyder and Cullen 2014; Vanlauwe et al. 2014; Pretty and Bharucha 2014; Caretta et al. 2018). Sustainable intensification defined by Pretty and Bharucha (2014) as 'a process or system where agricultural yields are increased without adverse environmental impact and without the conversion of additional non-agricultural land' is promoted by many research and development efforts as a sustainable pathway for agriculture in SSA. Sustainable intensification involves resource-conserving farm management practices including use of improved of crop varieties, integrated pest management, low-intensity grazing, minimum tillage, agroforestry, aquaculture, water harvesting and livestock integration (Bennett and Franzel 2013; Pretty and Bharucha 2014). In Kenya, such practices have the potential to improve the natural resource stock and consequently contribute to efforts towards poverty reduction and eradication of hunger, especially due to the positive relationship between soil fertility, biodiversity and plant productivity.

However, practices towards sustainable intensification need an enabling environment. For instance, given the positive relationship between property rights and land and water conservation reoccurring in this research and in literature (Shepherd and Soule 1998; Fraser 2004; Place 2009), and the role of land tenure security in resource conservation (Campbell et al. 2000; Kamau et al. 2018), the need to enhance land tenure security in smallholder farming is reinforced. The role of resource endowment in reinforcing sustainable farm management practices in smallholder farms is also crucial (Chapter 1) to counteract short-term oriented resource-depleting activities.

5.2.4 Future of organic agriculture in Kenya

In this research it was found that farms practicing OA have a higher stock of all types of the capital discussed above (Chapter 2), are modestly but significantly more sustainable (Chapter 3), and have higher levels of biodiversity (Chapter 3 and 4). Although qualitatively assessed to have higher soil and water quality due to lack of usage of synthetic pesticides (Chapter 3), quantitative analysis revealed that soil fertility did not differ in organic and conventional smallholder farms (Chapter 4). We attribute this to the almost similar farm management practices of smallholder farms in Kenya. Nonetheless, overall, OA practices do not reduce soil fertility and biodiversity in Kenya but might have the potential to improve these factors. Farms that are not organic certified need to be empowered to adopt more sustainable farming practices, which could begin with improving access to productive assets. We argue that OA can play an important role in improved natural resource conservation if smallholder farms are empowered in adopting management practices stipulated in the practice of OA. However, organic production per se may not improve sustainability in smallholder farms unless other measures such as capacity building, social security, and greater access to productive resources are considered. Nonetheless, if these factors are considered, we suggest that OA has the potential to improve the livelihoods of smallholders and the rural population in general, hence should be promoted.

5.3 Future research

This research provides an overview of the smallholder farm types that can be found in Kenya, their sustainability performance, and specifically how their farm management practices influence soil fertility and biodiversity. However, other issues that have not been considered in this research might be highly important when examining smallholder farms. First, it is recommended to use participatory approaches in farm typology construction in order to represent local realities (Alvarez et al. 2014; Kuivanen et al. 2016b, a), was not employed in this study. However, several informal meetings were held with farmers and other stakeholders in the agricultural sector in Kenya. Future research can use qualitative participatory approaches to complement quantitative statistical approaches for the development of farm typologies to increase the precision and applicability of typologies.

Secondly, because farms vary in space and over time, and farm typologies are dynamic, spatial and temporal data can aid in monitoring long-term change as well as in assessing the relationships between farm types and other landscape elements such as roads (Alvarez et al., 2014). However, spatial and time analyses require consistent, rich and high-resolution data, which is usually unavailable in developing countries like Kenya. Future studies can fill this gap by georeferencing farms and revisiting them on several occasions to monitor changes in farm types and sustainability performance over time.

Thirdly, this research did not determine causal relationships between different variables and aspects. For instance, although organic farms tended to be wealthier than non-organic farms, we could not determine if OA made the farms wealthier or if it was wealthier farms that practiced OA. Hence, research of organic and non-organic farms in Kenya that compares the farms before and after introduction of organic practices and the cause of conversion to organic production and/or certification and its effects on farmers well-being can provide a more conclusive answer on the impacts of OA.

Next, the sustainability assessment using the SMART-Farm Tool gives an overview of different sustainability aspects (Chapter 3). If smallholder farms perform poorly for a given factor, a more specific tool can be used to further explore this deficit. In line with this, we focused further research on soil fertility and biodiversity due to the persistent problem of land degradation in many countries in SSA, and provided several recommendations for its mitigation (Chapter 4). We would, however, also recommend further analysis of the other shortfalls in sustainability performance identified, and propose a number of possible future research questions and goals in this context:

- For animal husbandry practices: What are the impacts of animal husbandry practices on economic, environmental and social sustainability of smallholder farms, particularly in the highland areas of Kenya where average farm size is decreasing as population increases and land is subdivided into smaller portions? How much yield and revenue is lost because of poor livestock handling? What is the appropriate carrying capacity for farms practicing zero grazing in these regions? What are the effects of animal housing conditions on the health and safety of animals and workers in smallholder farms in Kenya? What are the environmental consequences of manure handling in smallholder farms? What kind of training programs and other interventions can be implemented to improve animal handling?
- For crop management: What kind of organic soil amendments can smallholders sustain to, among others, build organic soil matter given the rapid decomposition rates in tropical regions, affordability and limited land to allow fallow periods?
- For irrigated agriculture in ASAL areas: What are the most effective, available and affordable water-conserving technologies that can be adopted, and what kind of information can be provided to improve efficiency in water use?
- For capacity development to improve farm management knowledge and skills: How can the capacities of existing social networks of, for example women, farmer and church groups, be strengthened to raise awareness among farmers and rural communities? What are the context-specific knowledge and skill gaps among the informal workers in Kenya and how can these be filled?
- For improved support of vulnerable people: How can social protection programs be inclusive of the informal labor sector, particularly women and the youth?

In general, this research was limited in sample size and length of data collection, hence studies with larger samples sizes and longer study periods would yield more generalizable results. Nonetheless, the findings suggest that the highlighted sustainability issues are interlinked and that an integrated approach may have significant benefits in addressing barriers to economic, social and environmental sustainability in smallholder farming in Kenya and beyond rather than addressing each issue in isolation, thereby contributing to achievement of multiple SDGs.

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7 APPENDICES

Appendix A: Three principal components with loadings for each variable, their eigenvalues and percentage cumulative variance explained (Chapter 2).

	Principal Component		
Name of variable	PC1	PC2	PC3
Age of household head (hhh)	**-0.325**	**-0.449**	0.047
Total household (hh) size	-0.258	-0.077	0.066
Total years of education of hhh	**-0.339**	**0.529**	0.027
Ability of hhh to read and write	-0.145	**0.422**	0.111
Members working fulltime on-farm	0.057	-0.165	0.242
Members working part time on-farm	-0.014	0.014	0.183
Members working fulltime off-farm	-0.228	0.053	-0.067
Land legally owned in acres	**-0.478**	**-0.446**	-0.174
Land rented in acres	0.100	**0.549**	-0.135
Legally owned land cultivated	**-0.459**	**-0.481**	-0.157
Rented land cultivated acres	0.113	**0.569**	-0.147
Pure stands only	**-0.374**	-0.160	0.284
Intercropping only	0.108	0.119	**0.578**
Both pure-stands and intercrop	-0.013	-0.167	**-0.825**
Record keeping	-0.112	0.099	**0.506**
Mulching and cover cropping	**-0.513**	0.140	0.098
Use of organic soil additions	**-0.357**	-0.212	-0.120
Lack of use of any organic soil additions	**0.314**	0.191	0.136
Use of bio-pesticides	-0.251	0.122	-0.015
Intercropping with legumes	-0.133	-0.056	**-0.708**
Crop rotation	**-0.310**	0.262	0.051
Use of synthetic pesticides	0.062	**0.418**	-0.028
Use of mineral fertilizers	0.016	0.096	-0.012
Accessed credit in the last season	-0.224	**0.321**	0.126
Accessed credit in the last 2 years	-0.261	**0.396**	0.079
Accessed information on crop production	**-0.554**	0.129	0.098
Accessed information on input use	**-0.389**	0.122	-0.050
Heard of organic agriculture	**-0.574**	0.027	0.206
Practice of certified organic agriculture	**-0.407**	**-0.324**	0.288
Group membership (social networks)	**-0.437**	0.085	0.164
Crop income	**-0.531**	-0.060	0.100
Livestock income	**-0.445**	-0.030	-0.147
Income from other agricultural employment	-0.159	0.126	0.003
Income from non-agricultural employment	0.004	0.295	-0.225
Business income	-0.194	0.292	-0.273
Remittance income	-0.098	-0.144	-0.094

Appendix A: continued

Name of variable	Principal Component		
	PC1	PC2	PC3
Pension income	**-0.390**	-0.036	-0.145
Income from other sources	-0.036	-0.074	0.006
Crop gross margin	**-0.304**	-0.095	0.177
Ownership of productive assets (asset index)	**-0.495**	**0.391**	-0.231
Dietary diversity (dietary diversity index)	**-0.318**	**0.372**	-0.208
Livestock ownership in TLU	-0.030	-0.102	-0.071
Gender equity (gender index)	-0.217	0.054	-0.058
Eigenvalues	4.110	3.140	2.620
Cumulative variance explained (%)	82.100	86.700	90.400

Note. Numbers in bold refer to loadings greater than 0.3

Appendix B: Supplementary material for Chapter 3

Appendix B1: Subtheme objectives specified in the guidelines for Sustainability Assessment of Food and Agriculture Systems (SAFA Guidelines) (FAO 2014).

Dimension	Theme	Subtheme	Subtheme Objective
Good Governance	Corporate Ethics	Mission Statement	The enterprise has made its commitment to all areas of sustainability clear to the public, to all personnel and other stakeholders through publishing a mission statement or other similar declaration (such as a code of conduct or vision statement) that is binding for management and employees or members.
		Due Diligence	The enterprise is pro-active in considering its external impacts before making decisions that have long-term impacts for any area of sustainability. This is accomplished through the enterprise following appropriate procedures such as risk assessment and others that ensure that stakeholders are informed, engaged and respected.
	Accountability	Holistic Audits	All areas of sustainability in the SAFA dimensions that pertain to the enterprise are monitored internally in an appropriate manner, and wherever possible are reviewed according to recognized sustainability reporting systems.
		Responsibility	Senior management and/or owners of enterprise regularly and explicitly evaluate the enterprise's performance against its mission or code of conduct.
		Transparency	All procedures, policies, decisions or decision-making processes are accessible where appropriate publicly, and made available to stakeholders including personnel and others affected by the enterprise's activities.
	Participation	Stakeholder Dialogue	The enterprise pro-actively identifies stakeholders, which include all those affected by the activities of the enterprise (including any stakeholders unable to claim their rights), and ensures that all are informed, engaged in critical decision making, and that their input is duly considered.
		Grievance Procedures	All stakeholders (including as stated above, those who cannot claim their rights, personnel, and any stakeholders in or outside of the enterprise) have access to appropriate grievance procedures, without a risk of negative consequences.

Appendix B1: continued

Dimension	Theme	Subtheme	Subtheme Objective
		Conflict Resolution	Conflicts between stakeholder interests and the enterprise's activities are resolved through collaborative dialogue (i.e. arbitrated, mediated, facilitated, conciliated or negotiated), based on respect, mutual understanding and equal power.
	Rule of Law	Legitimacy	The enterprise is compliant with all applicable laws, regulations and standards voluntarily entered into by the enterprise (unless as part of an explicit campaign of non-violent civil disobedience or protest) and international human rights standards (whether legally obligated or not).
		Remedy, Restoration & Prevention	In case of any legal infringements or any other identified breach of legal, regulatory, international human rights, or voluntary standard, the enterprise immediately puts in place an effective remedy and adequate actions for restoration and further prevention are taken.
		Civic Responsibility	Within its sphere of influence, the enterprise supports the improvement of the legal and regulatory framework on all dimensions of sustainability and does not seek to avoid the impact of human rights, or sustainability standards, or regulation through the corporate veil, relocation, or any other means.
		Resource Appropriation	Enterprises do not reduce the existing rights of communities to land, water and resources, and operations are carried after informing affected communities by providing information, independent advice and building capacity to self- organize for the purposes of representation.
	Holistic Management	Sustainability Management Plan	A sustainability plan for the enterprise is developed which provides a holistic view of sustainability and considers synergies and trade-offs between dimensions, including each of the environmental, economic, social and governance dimensions.
		Full-Cost Accounting	The business success of the enterprise is measured and reported taking into account direct and indirect impacts on the economy, society and physical environment (e.g. triple bottom line reporting), and the accounting process makes transparent both direct and indirect subsidies received, as well as direct and indirect costs externalized.

Appendix B1: continued

Dimension	Theme	Subtheme	Subtheme Objective
Environmental Integrity	Atmosphere	Greenhouse Gases	The emission of GHG is contained.
		Air Quality	The emission of air pollutants is prevented and ozone depleting substances are eliminated.
	Water	Water Withdrawal	Withdrawal of ground and surface water and/or use does not impair the functioning of natural water cycles and ecosystems and human, plant and animal communities.
		Water Quality	The release of water pollutants is prevented and water quality is restored.
	Land	Soil Quality	Soil characteristics provide the best conditions for plant growth and soil health, while chemical and biological soil contamination is prevented.
		Land Degradation	No land is lost through soil degradation and desertification and degraded land is rehabilitated.
	Biodiversity	Ecosystem Diversity	The diversity, functional integrity and connectivity of natural, semi-natural and agrifood ecosystems are conserved and improved.
		Species Diversity	The diversity of wild species living in natural and semi-natural ecosystems, as well as the diversity of domesticated species living in agricultural, forestry and fisheries ecosystems is conserved and improved.
		Genetic Diversity	The diversity of populations of wild species, as well as the diversity of varieties, cultivars and breeds of domesticated species, is conserved and improved.
	Materials and Energy	Material Use	Material consumption is minimized and reuse, recycling and recovery rates are maximized.
		Energy Use	Overall energy consumption is minimized and use of sustainable renewable energy is maximized.
		Waste Reduction & Disposal	Waste generation is prevented and is disposed of in a way that does not threaten the health of humans and ecosystems and food loss/waste is minimized.
	Animal Welfare	Animal Health	Animals are kept free from hunger and thirst, injury and disease.
		Freedom from Stress	Animals are kept under species-appropriate conditions and free from discomfort, pain, injury and disease, fear and distress.

Appendix B1: continued

Dimension	Theme	Subtheme	Subtheme Objective
Economic Resilience	Investment	Internal Investment	In a continuous, foresighted manner, the enterprise invests into enhancing its sustainability performance.
		Community Investment	Through its investments, the enterprise contributes to sustainable development of a community.
		Long-Ranging Investment	Investments into production facilities, resources, market infrastructure, shares and acquisitions aim at long-term sustainability rather than maximum short-term profit.
		Profitability	Through its investments and business activities, the enterprise has the capacity to generate a positive net income.
	Vulnerability	Stability of Production	Production (quantity and quality) is sufficiently resilient to withstand and be adapted to environmental, social and economic shocks.
		Stability of Supply	Stable business relationships are maintained with a sufficient number of input suppliers and alternative procurement channels are accessible.
		Stability of Market	Stable business relationships are maintained with a sufficient number of buyers, income structure is diversified and alternative marketing channels are accessible.
		Liquidity	Financial liquidity, access to credits and insurance (formal and informal) against economic, environmental and social risk enable the enterprise to withstand shortfalls in payment.
		Risk Management	Strategies are in place to manage and mitigate the internal and external risks (i.e. price, production, market, credit, workforce, social, environmental) that the enterprise could face to withstand their negative impact.
	Product Quality & Information	Food Safety	Food hazards are systematically controlled and any contamination of food with potentially harmful substances is avoided.
		Food Quality	The quality of food products meets the highest nutritional standards applicable to the respective type of product.
		Product Information	Products bear complete information that is correct, by no means misleading and accessible for consumers and all members of the food chain.

Appendix B1: continued

Dimension	Theme	Subtheme	Subtheme Objective
Social Well-Being	Local Economy	Value Creation	Enterprises benefit local economies through employment and through payment of local taxes.
		Local Procurement	Enterprises substantially benefit local economies through procurement from local suppliers.
	Decent Livelihood	Quality of Life	All producers and employees in enterprises of all scales enjoy a livelihood that provides a culturally appropriate and nutritionally adequate diet and allows time for family, rest and culture.
		Capacity Development	Through training and education, all primary producers and personnel have opportunities to acquire the skills and knowledge necessary to undertake current and future tasks required by the enterprise, as well as the resources to provide for further training and education for themselves and members of their families.
		Fair Access to Means of Production	Primary producers have access to the means of production, including equipment, capital and knowledge.
	Fair Trading Practices	Responsible Buyers	The enterprise ensures that a fair price is established through negotiations with suppliers that allow them to earn and pay their own employees a living wage, and cover their costs of production, as well as maintain a high level of sustainability in their practices. Negotiations and contracts (verbal or written) are transparent, based on equal power, terminated only for just cause, and terms are mutually agreed upon.
		Rights of Suppliers	The enterprises negotiating a fair price explicitly recognize and support in good faith suppliers' rights to freedom of association and collective bargaining for all contracts and agreements.
	Labor Rights	Employment Relations	Enterprises maintain legally-binding transparent contracts with all employees that are accessible and cover the terms of work and employment is compliant with national laws on labor and social security.
		Forced Labor	The enterprise accepts no forced, bonded or involuntary labor, neither in its own operations nor those of business partners.

Appendix B1: continued

Dimension	Theme	Subtheme	Subtheme Objective
		Child Labor	The enterprise accepts no child labor that has a potential to harm the physical or mental health or hinder the education of minors, neither in its own operations nor those of business partners.
		Freedom of Association and Right to Bargaining	All persons in the enterprise can freely execute the rights to: negotiate the terms of their employment individually or as a group; form or adhere to an association defending workers' rights; and collectively bargain, without retribution.
	Equity	Non Discrimination	A strict equity and non-discrimination policy is pursued towards all stakeholders; non-discrimination and equal opportunities are explicitly mentioned in enterprise hiring policies, employee or personnel policies (whether written or verbal or code of conduct) and adequate means for implementation and evaluation are in place.
		Gender Equality	There is no gender disparity concerning hiring, remuneration, access to resources, education and career opportunities.
		Support to Vulnerable People	Vulnerable groups, such as young or elderly employees, women, the disabled, minorities and socially disadvantaged are proactively supported.
	Human Safety & Health	Workplace Safety and Health Provisions	The enterprise ensures that the workplace is safe, has met all appropriate regulations, and caters to the satisfaction of human needs in the provision of sanitary facilities, safe and ergonomic work environment, clean water, healthy food, and clean accommodation (if offered).
		Public Health	The enterprise ensures that operations and business activities do not limit the healthy and safe lifestyles of the local community and contributes to community health resources and services.
	Cultural Diversity	Indigenous Knowledge	Intellectual property rights related to traditional and cultural knowledge are protected and recognized.
		Food Sovereignty	The enterprise contributes to, and benefits from, exercising the right to choice and ownership of their production means, specifically in the preservation and use of traditional, heirloom and locally adapted varieties or breeds.

Appendix B2: High-impact indicators indicating poor performance in all sampled farms.

Dimension	Subtheme	Indicator long title	Average RI in %	Impact-weight (>0.6)
Good governance	Transparency	Publication of written commitment to sustainability	0	0.76
		Consideration of external environmental and social costs in the accounting procedure	0	0.61
		Explicit sustainability plan	0	0.75
		Communication with stakeholder groups	57	0.85
		Traceability of bought-in farm inputs	18	0.77
		Transparency of production	17	0.85
		Certification for the use of plant protection and animal treatment products	3	0.64
		Sustainability report publicly available	0	0.82
	Civic Responsibility	Involvement in improving laws and regulations	8	0.77
		Environmental involvement outside the farm: Costs	8	0.7
		Social involvement outside the farm: Costs	22	0.74
		Food security measures for local communities	23	0.67
	Full-Cost Accounting	Professional agricultural accounts	32	0.86
		Consideration of external environmental and social costs in the accounting procedure	0	0.84
	Mission Statement	Written commitment to sustainability	5	0.65
		Verbal commitment to sustainability	21	0.64
		Consideration of external environmental and social costs in the accounting procedure	0	0.63
		Explicit sustainability plan	0	0.71
		Oral information sustainability improvements	17	0.7

Appendix B2: continued

Dimension	Subtheme	Indicator long title		
Environmental Integrity	Ecosystem Diversity	Agro-forestry systems	8	0.77
		Ecological compensation areas: share of agricultural land	23	0.97
		Ecological compensation areas:	19	0.63
		On farm biodiversity promotion	42	0.61
Economic Resilience	Community Investment	Environmental involvement outside the farm: Costs	7	0.63
		Social involvement outside the farm: Costs	22	0.73
		Training on sustainability	37	0.74
		Ecological compensation areas: share of agricultural land	16	0.67
		Food security measures for local communities	21	0.62
		Number of jobs created/removed	39	0.77
		Ecological compensation areas	21	0.71
Social Well-Being	Capacity Development	Further training for farm staff	22	0.91
		Apprenticeships	0	0.64
		Training on sustainability	35	0.69
		Workers: Access to external training	1	0.77
		Workers: Training for use of plant protection and animal treatment products	9	0.69
		Access to advisory services	26	0.87
		Workers: Incidences of harassment and mobbing	70	0.7
		Anti-discrimination measures	44	0.81
		Disabled workers / inhabitants	4	0.64
	Support to Vulnerable People	Support disadvantaged groups	41	0.81
		Employee social protection	8	0.82

Appendix B3: Means of degree of goal achievement (DGA) for each subtheme by certification status and county, and significance levels for differences (letters indicate significant differences at p<0.05, ns = not significant). Cell colors indicate subthemes belonging to the same sustainability dimension.

	Certification Status			County			Certification Status and County			
Sub-theme	p	Certified	Non-certified	p	Murang'a	Kajiado	p	Certified x Murang'a	Certified x Kajiado	Non-certified x Murang'a	Non-certified x Kajiado
Mission Statement	p<0.05	35.7(±3)a	27.1(±1.9)b	ns	30.6(±2.1)a	32.2(±2.8)a	ns	34.1(±3.3)a	37.2(±5)a	27(±2.6)a	27.3(±2.7)a
Due Diligence	p<0.001	64.1(±1)a	59.2(±0.6)b	ns	62.7(±0.7)a	60.7(±1)a	p<0.01	63.3(±1.1)a	64.9(±1.7)a	62.1(±0.9)a	56.4(±0.9)
Holistic Audits	p<0.05	31.8(±1.6)a	27.1(±1)b	p<0.05	31.6(±1.1)	27.3(±1.5)	p<0.001	29.7(±1.7)a	33.9(±2.6)a	33.5(±1.4)a	20.6(±1.4)
Responsibility	p<0.01	42.5(±1.5)a	36.8(±1)b	ns	39.1(±1.1)a	40.2(±1.4)a	p<0.01	39(±1.7)a	45.9(±2.5)	39.3(±1.4)a	34.4(±1.4)
Transparency	p<0.001	31.1(±1.6)a	17.2(±1)b	p<0.001	27.9(±1.2)	20.5(±1.6)	ns	34.5(±1.8)	27.7(±2.7)	21.2(±1.5)	13.2(±1.5)
Stakeholder Dialogue	ns	80.7(±1.3)a	78.1(±0.8)a	ns	80.4(±0.9)a	78.4(±1.2)a	p<0.01	79.3(±1.5)a	82(±2.2)a	81.4(±1.2)a	74.8(±1.2)
Grievance Procedures	p<0.001	69.4(±1.4)a	63.5(±0.9)b	p<0.001	69.6(±1)	63.3(±1.3)	ns	70.9(±1.6)a	67.9(±2.3)a	68.3(±1.2)a	58.8(±1.3)
Conflict Resolution	ns	87.8(±1.3)a	86.8(±0.8)a	ns	88.5(±0.9)a	86.2(±1.2)a	p<0.05	86.9(±1.4)ab	88.8(±2.1)b	90.1(±1.1)b	83.6(±1.1)a
Legitimacy	p<0.01	71.3(±1.1)a	67.8(±0.7)b	p<0.01	71.6(±0.8)	67.5(±1.1)	ns	72.7(±1.2)a	69.9(±1.9)a	70.5(±1)a	65.1(±1)
Remedy, Restoration & Prevention	ns	81.3(±1.4)a	81.5(±0.9)a	ns	82.7(±1)a	80.1(±1.3)a	ns	81.4(±1.5)ab	81.3(±2.3)ab	84.1(±1.2)b	78.8(±1.2)a
Civic Responsibility	p<0.01	26.4(±2.3)a	18.2(±1.4)b	ns	20.3(±1.6)a	24.2(±2.1)a	p<0.01	19.9(±2.5)a	32.8(±3.7)	20.8(±2)a	15.7(±2)a
Resource Appropriation	ns	74(±1.1)a	72(±0.7)a	p<0.01	75(±0.8)	71(±1)	p<0.01	73.8(±1.2)a	74.1(±1.8)a	76.2(±0.9)a	67.8(±0.9)
Sustainability Management Plan	ns	44.8(±2.3)a	41.1(±1.4)a	ns	41.6(±1.6)a	44.3(±2.2)a	ns	41.2(±2.5)a	48.4(±3.8)a	42.1(±2)a	40.2(±2)a
Full-Cost Accounting	p<0.05	35.7(±3)a	27.3(±1.9)b	ns	30.6(±2.1)a	32.4(±2.8)a	ns	34.1(±3.3)a	37.3(±4.9)a	27.1(±2.6)a	27.5(±2.7)a
Greenhouse Gases	ns	53.2(±0.5)a	52.6(±0.3)a	p<0.001	51(±0.4)	54.8(±0.5)	ns	51.1(±0.6)a	55.3(±0.8)b	50.9(±0.4)a	54.3(±0.5)b
Air Quality	ns	60.8(±0.6)a	60.2(±0.4)a	p<0.001	59(±0.4)	61.9(±0.6)	ns	59.2(±0.7)a	62.4(±1)b	58.9(±0.6)a	61.4(±0.6)b
Water Withdrawal	ns	58.7(±1.2)a	56.3(±0.7)a	p<0.001	60.4(±0.8)	54.5(±1.1)	ns	61.1(±1.3)c	56.3(±1.9)ab	59.8(±1)bc	52.8(±1)a
Water Quality	p<0.01	66.1(±0.7)a	63.2(±0.4)b	ns	64(±0.5)a	65.4(±0.7)a	ns	65.9(±0.8)a	66.4(±1.2)a	62.1(±0.6)	64.4(±0.6)a
Soil Quality	p<0.05	60.2(±0.5)a	58.4(±0.3)b	ns	59.3(±0.4)a	59.3(±0.5)a	ns	60.2(±0.6)b	60.1(±0.9)ab	58.4(±0.5)a	58.4(±0.5)a
Land Degradation	ns	63(±0.5)a	62.1(±0.3)a	p<0.05	61.9(±0.4)	63.1(±0.5)	ns	62.2(±0.6)ab	63.7(±0.8)b	61.6(±0.4)a	62.5(±0.4)ab
Ecosystem Diversity	p<0.01	49.1(±0.9)a	46(±0.6)b	ns	47.6(±0.6)a	47.5(±0.8)a	ns	48.9(±1)c	49.4(±1.5)bc	46.4(±0.8)ab	45.6(±0.8)a
Species Diversity	p<0.001	62.1(±0.7)a	58.8(±0.4)b	ns	60.4(±0.5)a	60.6(±0.7)a	ns	61.6(±0.8)b	62.7(±1.2)b	59.1(±0.6)a	58.5(±0.6)a

Appendix B3: continued

Sub-theme	Certification Status p	Certified	Non-certified	County p	Murang'a	Kajiado	Certification Status and County p	Certified x Murang'a	Certified x Kajiado	Non-certified x Murang'a	Non-certified x Kajiado
Genetic Diversity	p<0.001	56.1(±0.8)a	52.6(±0.5)b	p<0.01	55.9(±0.6)	52.8(±0.8)	p<0.05	56.5(±0.9)a	55.8(±1.4)a	55.4(±0.7)a	49.8(±0.7)
Material Use	ns	56.4(±0.9)a	55.2(±0.6)a	ns	55.8(±0.6)a	55.8(±0.8)a	ns	56.5(±1)a	56.2(±1.5)a	55(±0.8)a	55.4(±0.8)a
Energy Use	ns	57.3(±0.6)a	58.2(±0.4)a	ns	57.5(±0.4)a	58(±0.5)a	ns	56.8(±0.6)a	57.7(±1)a	58.2(±0.5)a	58.3(±0.5)a
Waste Reduction & Disposal	ns	62.4(±1)a	60.4(±0.6)a	ns	61.4(±0.7)a	61.3(±0.9)a	ns	63.3(±1.1)b	61.5(±1.6)ab	59.6(±0.8)a	61.2(±0.9)ab
Animal Health	ns	67.1(±1.2)a	66.7(±0.7)a	p<0.001	63.8(±0.8)	70(±1.1)	ns	62.9(±1.3)a	71.3(±2)b	64.7(±1)a	68.6(±1.1)b
Freedom from Stress	ns	63.1(±1.2)a	63.2(±0.8)a	p<0.001	59.4(±0.9)	66.9(±1.1)	ns	58.2(±1.3)a	68(±2)b	60.5(±1.1)a	65.8(±1.1)b
Internal Investment	ns	52.4(±0.9)a	50.5(±0.5)a	p<0.05	52.7(±0.6)	50.2(±0.8)	ns	53.4(±1)b	51.5(±1.4)ab	52(±0.8)b	48.9(±0.8)a
Community Investment	p<0.001	39.8(±1.2)a	34.7(±0.7)b	ns	37.1(±0.8)a	37.4(±1.1)a	p<0.05	38.1(±1.3)bc	41.5(±1.9)c	36(±1)ab	33.3(±1)a
Long-Ranging Investment	p<0.05	57.5(±1)a	54.2(±0.7)b	p<0.05	57.2(±0.7)	54.5(±1)	p<0.01	56.8(±1.2)a	58.2(±1.7)a	57.7(±0.9)a	50.7(±0.9)
Profitability	ns	53.6(±0.7)a	54.3(±0.4)a	p<0.01	55.2(±0.5)	52.7(±0.6)	ns	55.1(±0.8)bc	52.2(±1.1)a	55.3(±0.6)c	53.3(±0.6)ab
Stability of Production	ns	57.8(±0.7)a	58.1(±0.5)a	ns	58.5(±0.5)a	57.4(±0.7)a	p<0.05	57.4(±0.8)a	58.2(±1.2)ab	59.6(±0.6)b	56.5(±0.7)a
Stability of Supply	ns	55.5(±0.8)a	55.2(±0.5)a	p<0.05	54.3(±0.6)	56.4(±0.8)	p<0.01	53(±0.9)a	58(±1.3)c	55.5(±0.7)bc	54.9(±0.7)ab
Stability of Market	p<0.001	60.4(±0.9)a	55.3(±0.6)b	p<0.001	61.6(±0.7)	54(±0.9)	ns	65.1(±1)	55.6(±1.6)ab	58.1(±0.8)b	52.4(±0.8)a
Liquidity	p<0.05	53.1(±1.3)a	49.9(±0.8)b	p<0.05	53.6(±0.9)	49.4(±1.3)	ns	56.3(±1.5)	49.9(±2.2)a	50.8(±1.2)a	48.9(±1.2)a
Risk Management	p<0.001	68.3(±0.7)a	64.9(±0.4)b	ns	66.3(±0.5)a	66.9(±0.6)a	p<0.05	67(±0.8)bc	69.5(±1.1)c	65.5(±0.6)ab	64.4(±0.6)a
Food Safety	p<0.001	74.8(±0.8)a	70.3(±0.5)b	p<0.05	73.8(±0.6)	71.4(±0.8)	ns	75.4(±0.9)b	74.3(±1.3)ab	72.2(±0.7)a	68.4(±0.7)
Food Quality	ns	69.1(±0.9)a	67.4(±0.6)a	p<0.05	69.8(±0.7)	66.8(±0.9)	ns	70(±1)b	68.3(±1.5)ab	69.5(±0.8)b	65.4(±0.8)a
Product Information	p<0.001	44.9(±1.7)a	33.6(±1.1)b	p<0.001	44.5(±1.2)	33.9(±1.6)	ns	48.7(±1.9)	41(±2.8)a	40.3(±1.5)a	26.9(±1.5)
Value Creation	ns	40.8(±0.8)a	40(±0.5)a	ns	40.1(±0.5)a	40.7(±0.7)a	p<0.01	38.9(±0.9)a	42.6(±1.3)b	41.2(±0.7)b	38.9(±0.7)a
Local Procurement	ns	40.4(±1.9)a	43.9(±1.2)a	ns	42.9(±1.4)a	41.4(±1.8)a	p<0.001	36.9(±2.1)a	43.8(±3.2)ab	48.9(±1.7)b	38.9(±1.7)a
Quality of Life	ns	69.1(±0.6)a	68(±0.4)a	ns	68.4(±0.5)a	68.6(±0.6)a	p<0.01	67.7(±0.7)ab	70.4(±1.1)c	69.2(±0.6)bc	66.8(±0.6)a
Capacity Development	p<0.001	23(±1.8)a	13.6(±1.1)b	ns	17.5(±1.3)a	19(±1.7)a	ns	20.2(±2)b	25.7(±3)b	14.8(±1.6)a	12.3(±1.6)a
Fair Access to Means of Production	p<0.05	68(±1.3)a	64.6(±0.8)b	ns	67.5(±0.9)a	65.1(±1.2)a	p<0.05	67.2(±1.4)a	68.8(±2.1)a	67.9(±1.1)a	61.4(±1.1)

Appendix B3: continued

Sub-theme	Certification Status p	Certified	Non-certified	County p	Murang'a	Kajiado	Certification Status and County p	Certified x Murang'a	Certified x Kajiado	Non-certified x Murang'a	Non-certified x Kajiado
Responsible Buyers	ns	63.2(±0.9)a	64.2(±0.6)a	ns	63.9(±0.6)a	63.6(±0.9)a	p<0.001	61.3(±1)a	65.2(±1.5)bc	66.5(±0.8)c	62(±0.8)ab
Rights of Suppliers	ns	59.3(±1.1)a	59.8(±0.7)a	ns	58.3(±0.8)a	60.7(±1)a	p<0.01	55.9(±1.2)a	62.6(±1.8)b	60.8(±0.9)b	58.8(±1)ab
Employment Relations	ns	70.1(±0.6)a	69.1(±0.4)a	ns	70(±0.4)a	69.3(±0.6)a	ns	69.9(±0.7)b	70.4(±1)ab	70.1(±0.5)b	68.1(±0.6)a
Forced Labor	p<0.001	66.3(±0.9)a	60.2(±0.6)b	p<0.01	65.1(±0.7)	61.4(±0.9)	ns	67.5(±1)b	65.1(±1.6)ab	62.6(±0.8)a	57.7(±0.8)
Child Labor	p<0.001	77(±0.8)a	72.5(±0.5)b	p<0.001	77.8(±0.6)	71.7(±0.8)	p<0.05	79(±0.9)	75.1(±1.4)a	76.5(±0.7)a	68.4(±0.8)
Freedom of Association and Right to Bargaining	p<0.001	54(±1)a	46.8(±0.6)b	ns	51(±0.7)a	49.7(±0.9)a	ns	53.6(±1.1)a	54.3(±1.6)a	48.3(±0.9)	45.2(±0.9)
Non Discrimination	ns	65.8(±1.3)a	65.8(±0.8)a	ns	66.4(±0.9)a	65.2(±1.2)a	ns	65.6(±1.4)a	66(±2.1)a	67.2(±1.1)a	64.5(±1.1)a
Gender Equality	ns	70.9(±2)a	71.5(±1.2)a	ns	72.2(±1.4)a	70.2(±1.9)a	ns	71.1(±2.2)a	70.7(±3.3)a	73.3(±1.7)a	69.7(±1.8)a
Support to Vulnerable People	p<0.001	41.4(±1.2)a	35.6(±0.7)b	ns	38.3(±0.8)a	38.7(±1.1)a	ns	40.1(±1.3)b	42.8(±1.9)b	36.6(±1)a	34.7(±1)a
Workplace Safety and Health Provisions	p<0.01	71(±0.8)a	68(±0.5)b	ns	69.7(±0.5)a	69.3(±0.7)a	p<0.05	70.1(±0.8)a	71.9(±1.3)a	69.4(±0.7)a	66.7(±0.7)
Public Health	p<0.001	77(±0.9)a	73.2(±0.6)	ns	75(±0.6)a	75.2(±0.8)a	ns	76.4(±1)b	77.7(±1.5)b	73.7(±0.8)a	72.7(±0.8)a
Indigenous Knowledge	ns	82(±1.4)a	80.4(±0.9)a	p<0.01	83.9(±1)	78.5(±1.4)	ns	83.7(±1.6)b	80.3(±2.4)ab	84.2(±1.3)b	76.6(±1.3)a
Food Sovereignty	ns	66.8(±1)a	64.8(±0.7)a	ns	66.5(±0.7)a	65.1(±1)a	p<0.01	65.5(±1.2)a	68.1(±1.7)a	67.5(±0.9)a	62.1(±0.9)

Appendix B4: Means of degree of goal achievement (DGA) for each subtheme by farm type and county, and significance levels for differences (letters indicate significant differences at p<0.05, ns = not significant). Cell colors indicate subthemes belonging to the same sustainability dimension.

	Farm type						**County**			**Farm type x County**
Sub-theme	p	Type1	Type2	Type3	Type4	Type5	p	Murang'a	Kajido	p
Mission Statement	ns	26.4(4.2)	34.0(3.0)	30.1(3.4)	32.9(4.5)	24.0(3.2)	ns	30.4(2.2)	28.6(2.5)	ns
Due Diligence	ns	61.1(1.5)	61.1(1.0)	59.3(1.2)	61.3(1.6)	60.3(1.1)	<0.001	63.3(0.8)a	58.0(0.9)b	<0.05
Holistic Audits	ns	29.3(2.3)	26.5(1.6)	28.2(1.8)	27.4(2.4)	28.7(1.7)	<0.001	32.7(1.2)a	23.4(1.3)b	ns
Responsibility	ns	38.0(2.2)	38.3(1.5)	38.7(1.8)	40.7(2.4)	36.2(1.7)	ns	39.9(1.2)	36.9(1.3)	ns
Transparency	ns	20.8(2.4)	21.0(1.7)	24.2(2.0)	22.2(2.7)	20.1(1.9)	<0.001	27.4(1.3)a	15.9(1.4)b	ns
Stakeholder Dialogue	ns	80.7(1.9)	78.7(1.3)	78.7(1.5)	79.6(2.0)	76.9(1.4)	<0.01	81.4(1.0)a	76.4(1.0)b	ns
Grievance Procedures	ns	68.6(2.0)	65.2(1.4)	64.5(1.6)	67.4(2.1)	62.7(1.5)	<0.001	70.2(1.1)a	61.1(1.2)b	ns
Conflict Resolution	ns	89.5(1.8)	87.1(1.3)	87.5(1.5)	86.6(1.9)	85.1(1.4)	<0.01	89.6(1.0)a	84.7(1.0)b	<0.05
Legitimacy	ns	69.7(1.6)	70.1(1.1)	67.5(1.3)	70.5(1.7)	67.0(1.2)	<0.001	71.9(0.8)a	66.0(0.9)b	ns
Remedy, Restoration & Prevention	ns	83.9(1.9)	83.6(1.3)	80.0(1.6)	81.7(2.1)	78.2(1.5)	<0.05	83.6(1.0)a	79.4(1.5)b	ns
Civic Responsibility	ns	18.3(3.2)	20.5(2.3)	18.5(2.6)	26.3(3.5)	19.0(2.5)	ns	21.5(1.7)	19.6(1.9)	ns
Resource Appropriation	ns	73.4(1.5)	74.0(1.0)	71.8(1.2)	71.6(1.6)	71.0(1.1)	<0.001	75.8(0.8)a	68.9(0.9)b	<0.05
Sustainability Management Plan	ns	39.7(3.2)	43.5(2.3)	43.2(2.6)	43.5(3.5)	39.1(2.5)	ns	41.9(1.7)	41.6(1.9)	ns
Full-Cost Accounting	ns	26.4(4.2)	34.3(2.9)	30.1(3.3)	33.0(4.5)	24.2(3.2)	ns	30.4(2.2)	28.8(2.4)	ns
Greenhouse Gases	ns	53.5(0.7)	53.1(0.5)	52.3(0.6)	52.9(0.8)	52.2(0.5)	<0.001	51.0(0.4)a	54.6(0.4)b	ns
Air Quality	ns	61.6(0.9)	60.7(0.6)	59.4(0.7)	60.6(1.0)	59.7(0.7)	<0.001	59.1(0.5)a	61.7(0.5)b	ns
Water Withdrawal	ns	57.3(1.6)	58.5(1.1)	54.5(1.3)	59.5(1.7)	56.0(1.2)	<0.001	60.7(0.9)a	53.6(0.9)b	ns
Water Quality	ns	65.3(1.0)	64.6(0.7)	63.5(0.8)	63.4(1.1)	64.8(1.1)	ns	63.9(0.5)	64.8(0.6)	ns
Soil Quality	ns	58.9(0.7)	59.1(0.5)	58.9(0.6)	59.5(0.8)	58.5(0.6)	ns	59.3(0.4)	58.7(0.4)	ns
Land Degradation	ns	61.9(0.7)	61.9(0.5)	62.8(0.6)	62.8(0.8)	62.4(0.5)	ns	62.0(0.4)	62.8(0.4)	ns
Ecosystem Diversity	ns	45.8(1.3)	46.0(0.9)	47.8(1.0)	47.1(1.4)	47.8(1.0)	ns	47.4(0.7)	46.3(0.7)	ns
Species Diversity	ns	59.7(1.0)	59.6(0.7)	60.0(0.8)	60.0(1.1)	59.8(0.8)	ns	60.2(0.5)	59.5(0.6)	ns

Appendix B4: continued

		Farm type						County		Farm type x County
Sub-theme	p	Type1	Type2	Type3	Type4	Type5	p	Murang'a	Kajido	p
Genetic Diversity	ns	52.5(1.2)	53.2(0.8)	54.1(1.0)	54.1(1.3)	53.6(0.9)	<0.001	56.0(0.6)a	51.0(0.7)b	ns
Material Use	ns	56.8(1.2)	55.9(0.9)	54.4(1.0)	55.5(1.3)	55.4(1.0)	ns	55.4(0.7)	55.8(0.7)	ns
Energy Use	ns	59.4(0.8)	57.7(0.6)	57.7(0.7)	57.2(0.9)	57.7(0.6)	ns	57.4(0.4)	58.4(0.5)	ns
Waste Reduction & Disposal	ns	63.1(1.4)	62.3(0.9)	59.4(1.1)	61.5(1.5)	59.8(1.0)	ns	61.1(0.7)	61.4(0.8)	ns
Animal Health	ns	65.9(1.7)	68.0(1.2)	65.8(1.3)	68.2(1.8)	65.3(1.3)	<0.001	64.2(0.9)a	69.1(1.0)b	ns
Freedom from Stress	ns	62.0(1.7)	63.9(1.2)	62.7(1.4)	64.7(1.8)	61.7(1.3)	<0.001	59.9(0.9)a	66.2(1.0)b	ns
Internal Investment	ns	49.1(1.2)	51.6(0.9)	50.7(1.0)	51.7(1.3)	49.4(0.7)	<0.01	52.4(0.6)a	49.4(0.7)b	ns
Community Investment	ns	34.6(1.7)	35.9(1.2)	35.4(1.4)	38.0(1.8)	36.8(1.3)	ns	37.4(0.9)	34.9(1.0)	ns
Long-Ranging Investment	ns	52.6(1.5)	54.9(1.0)	54.6(1.2)	56.6(1.6)	55.8(1.1)	<0.001	57.6(0.8)a	52.2(0.9)b	ns
Profitability	ns	53.1(1.0)	55.5(0.7)	53.9(0.8)	54.9(1.0)	52.9(0.7)	<0.05	55.2(0.5)a	52.9(0.6)b	ns
Stability of Production	ns	57.0(1.0)	58.6(0.7)	58.1(0.8)	57.9(1.1)	57.1(0.8)	<0.05	58.7(0.6)a	56.7(0.6)b	ns
Stability of Supply	ns	55.6(1.2)	55.9(0.8)	54.6(0.9)	55.4(1.2)	54.1(0.9)	ns	54.7(0.6)	55.6(0.7)	ns
Stability of Market	ns	55.9(1.4)	57.3(1.0)	58.1(1.1)	57.6(1.5)	56.1(1.1)	<0.001	61.2(0.7)a	52.8(0.8)b	ns
Liquidity	ns	48.1(1.9)	52.8(1.3)	50.6(1.5)	51.9(2.0)	51.1(1.4)	<0.05	53.2(1.0)a	48.6(1.1)b	ns
Risk Management	ns	66.1(1.0)	65.9(0.7)	65.9(0.8)	66.2(1.1)	65.4(0.7)	ns	66.3(0.5)	65.5(0.6)	ns
Food Safety	ns	72.8(1.2)	72.4(0.8)	70.8(0.9)	71.8(1.3)	70.7(0.9)	<0.001	73.7(0.6)a	69.7(0.7)b	ns
Food Quality	ns	68.4(1.3)	68.7(0.9)	67.3(1.0)	66.9(1.4)	67.6(1.0)	<0.001	69.8(0.7)a	65.8(0.8)b	ns
Product Information	ns	36.9(2.4)	34.5(1.7)	39.0(2.0)	38.4(2.6)	37.4(1.9)	<0.001	44.7(1.3)a	29.7(1.4)b	ns
Value Creation	ns	38.5(1.1)	41.0(0.8)	39.4(0.9)	41.5(1.2)	39.7(0.8)	ns	40.5(0.6)	39.6(0.6)	<0.05
Local Procurement	ns	37.4(2.8)	43.8(1.9)	42.5(2.2)	45.8(3.0)	41.4(2.1)	<0.05	44.7(1.5)a	39.6(1.6)b	<0.05
Quality of Life	ns	68.6(0.9)	69.1(0.6)	66.6(0.7)	68.4(1.0)	68.0(0.7)	ns	68.8(0.5)	67.5(0.5)	<0.05
Capacity Development	ns	14.7(2.6)	16.8(1.8)	17.0(2.1)	15.6(2.8)	15.8(2.0)	ns	16.6(1.4)	15.4(1.5)	ns
Fair Access to Means of Production	ns	66.2(1.8)	67.2(1.3)	65.2(1.4)	64.1(1.9)	63.7(1.4)	<0.01	67.6(0.9)a	63.0(1.0)b	ns
Responsible Buyers	ns	64.9(1.3)	62.8(0.9)	64.0(1.1)	63.8(1.4)	63.4(1.0)	ns	64.7(0.7)	62.8(0.8)	ns

Appendix B4: continued

		Farm type						County		Farm type x County
Sub-theme	p	Type1	Type2	Type3	Type4	Type5	p	Murang'a	Kajido	p
Rights of Suppliers	ns	61.2(1.5)	56.7(1.1)	60.9(1.2)	59.6(1.6)	59.5(1.2)	ns	59.0(0.8)	60.2(0.9)	ns
Employment Relations	ns	70.2(0.9)	69.6(0.6)	68.6(0.7)	70.5(0.9)	68.5(0.7)	ns	70.1(0.5)	68.9(0.5)	ns
Forced Labor	<0.05	65.6(1.4)c	60.1(1.0)a	61.8(1.1)ab	64.2(1.5)bc	61.2(1.0)ab	<0.001	65.2(0.7)a	59.9(0.8)b	ns
Child Labor	ns	75.6(1.2)	72.7(0.9)	73.6(1.0)	74.5(1.3)	73.6(0.9)	<0.001	78.0(0.6)a	70.0(0.7)b	ns
Freedom of Association and Right to Bargaining	ns	52.2(1.4)c	48.0(1.0)b	48.6(1.5)b	49.7(1.5)bc	47.8(1.1)	<0.01	51.0(0.8)a	47.6(0.8)b	ns
Non Discrimination	ns	65.8(1.8)	66.2(1.2)	65.3(1.4)	67.5(1.9)	64.3(1.3)	ns	67.2(0.9)	64.5(1.0)	ns
Gender Equality	ns	71.1(2.8)	72.0(1.9)	70.1(2.2)	73.6(3.0)	69.8(2.1)	ns	73.3(1.5)	69.3(1.6)	ns
Support to Vulnerable People	ns	37.9(1.7)	37.3(1.2)	36.9(1.4)	38.0(1.8)	36.9(1.3)	ns	38.6(0.9)	36.1(1.0)	ns
Workplace Safety and Health Provisions	ns	69.6(1.1)	69.7(0.8)	68.0(0.9)	68.5(1.2)	68.2(0.8)	<0.05	69.9(0.6)a	67.7(0.6)b	ns
Public Health	ns	75.9(1.3)	75.0(0.9)	73.0(1.0)	75.5(1.4)	73.6(1.0)	ns	75.3(0.7)	73.8(0.7)	ns
Indigenous Knowledge	ns	79.5(2.0)	83.6(1.4)	78.4(1.6)	81.3(2.1)	80.6(1.5)	<0.001	84.6(1.1)a	76.8(1.2)b	<0.01
Food Sovereignty	ns	64.0(1.5)	66.3(1.0)	64.3(1.2)	66.1(1.6)	64.7(1.1)	<0.05	66.8(0.8)a	63.3(0.9)b	ns

Appendix B5: High-impact indicators indicating differences in sustainability performance between certified and non-certified farms.

			Average RI in percentage		
Dimension	Subtheme	Indicator title	Certified	Non-certified	(C-NC)[1]
Good Governance	DueDiligence	SupportDisadvantagedGroups	65	28	37
	FullCostAccounting	ProfessionalAgriculturalAccounts	43	31	12
	GrievanceProcedures	EmployeesLegallyBindingContracts	21	10	11
	GrievanceProcedures	SupportDisadvantagedGroups	70	30	40
	HolisticAudits	ProfessionalAgriculturalAccounts	36	26	10
	HolisticAudits	EnvironmentallyCertifiedProducts	29	9	20
	HolisticAudits	MineralKFertilizers	6	19	-13
	HolisticAudits	AnimalWelfareStandardsSlaughter	23	35	-12
	Legitimacy	WasteDisposalPesticidesVeterinaryMedicines	66	51	16
	Legitimacy	EmployeesLegallyBindingContracts	23	11	12
	StakeholderDialogue	SupportDisadvantagedGroups	58	25	33
	SustainabilityManagementPlan	SustainabilityTraining	0	37	-37
	Transparency	TrasparencyProduction	33	9	24
Environmental Integrity	AnimalHealth	AccessToPasture	4	14	-10
	AnimalHealth	InjuriesPigs	45	73	-27
	AnimalHealth	BuyingNewAnimals	39	28	11
	AnimalHealth	PigsQuarantine	43	26	17
	EcosystemDiversity	PermanentGrasslandsExtensivelyManaged	5	17	-12
	FreedomFromStress	MutilationAnaestheticsAnalgesics	31	53	-23
	FreedomFromStress	AccessToPasture	5	18	-13
	FreedomFromStress	AnimalWelfareStandardsSlaughter	21	32	-11
	FreedomFromStress	InjuriesPigs	43	68	-26

Appendix B5: continued

			Average RI in percentage		
Dimension	Subtheme	Indicator title	Certified	Non-certified	(C-NC)[1]
	FreedomFromStress	PolishTeethPiglets	68	47	20
	FreedomFromStress	PigsNoseRing	68	54	14
	MaterialUse	MineralKFertilizers	6	19	-13
	MaterialUse	FoodWaste	44	55	-11
	SoilQuality	WasteDisposalPesticidesVeterinaryMedicines	49	37	12
	SpeciesDiversity	NumberScatteredFruitTrees	49	39	11
	SpeciesDiversity	PermanentGrasslandsExtensivelyManaged	5	17	-12
	WasteReductionDisposal	WasteDisposalPesticidesVeterinaryMedicines	70	54	17
	WasteReductionDisposal	RecyclingPaper	30	20	10
	WasteReductionDisposal	FoodWaste	55	69	-14
	WaterQuality	WasteDisposalPesticidesVeterinaryMedicines	67	51	16
	WaterQuality	WastewaterDisposal	54	41	12
	WaterWithdrawal	WaterUseEfficiency	55	42	14
Economic Resilience	CommunityInvestment	SustainabilityTraining	0	40	-40
	FoodQuality	EnvironmentallyCertifiedProducts	29	9	20
	FoodQuality	AccessToPasture	4	14	-10
	FoodSafety	EnvironmentallyCertifiedProducts	27	9	18
	FoodSafety	TrasparencyProduction	26	7	19
	FoodSafety	TrainingUsagePlantProtectionAnimalTreatmentProducts	18	9	10
	InternalInvestment	FarmStaffTraining	28	15	13

Appendix B5: continued

			Average RI in percentage		
Dimension	Subtheme	Indicator title	Certified	Non-certified	(C-NC)[1]
	InternalInvestment	LongTermInvestments	58	47	11
	Liquidity	DiversificationIncome	49	28	21
	LocalProcurement	LocalProcurementProducerLevel	24	35	-10
	LongRangingInvestment	FarmStaffTraining	26	14	12
	LongRangingInvestment	LongTermInvestments	57	46	10
	ProductInformation	EnvironmentallyCertifiedProducts	29	9	20
	ProductInformation	ProductsSocialStandards	30	10	20
	ProductInformation	TrasparencyProduction	34	9	24
	Profitability	ProfessionalAgriculturalAccounts	40	29	11
	Profitability	YieldLoss	29	42	-13
	Profitability	DiversificationIncome	45	26	19
	RiskManagement	ProfessionalAgriculturalAccounts	37	27	10
	RiskManagement	DiversificationIncome	54	31	23
	RiskManagement	BuyingNewAnimals	44	32	12
	StabilityOfMarket	SalesDiversification	64	54	10
	StabilityOfMarket	DiversificationIncome	49	28	21
	StabilityOfMarket	TrasparencyProduction	23	6	17
	StabilityOfProduction	YieldLoss	31	44	-13
	StabilityOfProduction	InjuriesPigs	29	46	-17
	ValueCreation	LocalProcurementProducerLevel	24	35	-10
Social	AccessToProductionMeans	FarmStaffTraining	23	13	11
Well-Being	AccessToProductionMeans	AccessAdvisoryServices	31	21	10
	AssociationAndBargainingRight	EmployeesLegallyBindingContracts	20	9	10
	CapacityDevelopment	FarmStaffTraining	32	18	15

Appendix B5: continued

			Average RI in percentage		
Dimension	Subtheme	Indicator title	Certified	Non-certified	(C-NC)[1]
	CapacityDevelopment	SustainabilityTraining	0	38	-38
	CapacityDevelopment	AccessAdvisoryServices	34	23	11
	EmploymentRelations	EmployeesLegallyBindingContracts	23	11	12
	ForcedLabor	EmployeesLegallyBindingContracts	22	10	12
	GenderEquality	SupportDisadvantagedGroups	78	33	44
	PublicHealth	WasteDisposalPesticidesVeterinaryMedicines	60	46	14
	PublicHealth	WastewaterDisposal	55	42	13
	QualityOfLife	SupportDisadvantagedGroups	61	26	35
	SupportToVulnerablePeople	SupportDisadvantagedGroups	81	35	46
	WorkplaceSafetyAndHealthProvisions	WasteDisposalPesticidesVeterinaryMedicines	62	47	15
	WorkplaceSafetyAndHealthProvisions	PigsQuarantine	50	30	20

[1] *represents differences in average RI scores between Certified (C) and Non-certified (NC) fa*

Appendix B6: High-impact indicators indicating differences in sustainability performance across the five farm types.

			Average RI in percentage				
Dimension	Subtheme	Indicator title	1	2	3	4	5
Social well-being	Forced Labor	SocialResponsibilityProcurement	13	13	21	21	9
		ProductsSocialStandards	26	17	21	8	23
		EmployeesWorkPermit	79	69	79	79	79
		EmployeesLegallyBindingContracts	17	16	0	0	0
		Forced Labor	70	70	70	70	70
		SuppliersForced Labor	74	74	74	74	74
		EmpolyeeFreedomJoiningUnions	50	51	51	58	58
		EmployeeSocialProtection	4	4	0	0	4
		FarmInputsCountriesProblematicSocialCondition	56	56	56	56	56

Appendix B7: High impact indicators indicating differences in sustainability performance between farms sampled in Kajiado and Murang'a counties.

Dimension	Subtheme	Indicator title	Average RI in percentage		
			Kajiado	Murang'a	(M-K)[1]
Good Governance	ConflictResolution	CommunicationStakeholder	70	58	-12
	ConflictResolution	PreventionResourceConflicts	47	60	13
	ConflictResolution	SupportDisadvantagedGroups	52	10	-42
	DueDiligence	EnvironmentallyCertifiedProducts	4	21	17
	DueDiligence	ProductsSocialStandards	4	19	16
	DueDiligence	PreventionResourceConflicts	36	47	10
	DueDiligence	SupportDisadvantagedGroups	65	13	-52
	GrievanceProcedures	ProductsSocialStandards	3	18	15
	GrievanceProcedures	PreventionResourceConflicts	44	56	12
	GrievanceProcedures	SupportDisadvantagedGroups	70	14	-56
	HolisticAudits	ProfessionalAgriculturalAccounts	36	18	-18
	HolisticAudits	EnvironmentallyCertifiedProducts	5	25	20
	HolisticAudits	ProductsSocialStandards	3	19	15
	HolisticAudits	HumusFormationHumusBalance	36	46	10
	Legitimacy	PreventionResourceConflicts	42	53	12
	Legitimacy	WasteDisposalPesticidesVeterinaryMedicines	50	61	11
	RemedyRestorationPrevention	PreventionResourceConflicts	50	64	14
	ResourceAppropriation	CommunicationStakeholder	62	52	-10
	ResourceAppropriation	ProductsSocialStandards	3	14	11
	ResourceAppropriation	PreventionResourceConflicts	55	71	16
	ResourceAppropriation	InformationWaterAvailability	32	46	13
	StakeholderDialogue	CommunicationStakeholder	64	54	-11

Appendix B7: continued

Dimension	Subtheme	Indicator title	Average RI in percentage		
			Kajiado	Murang'a	(M-K)[1]
			47	61	13
	StakeholderDialogue	SupportDisadvantagedGroups	58	12	-46
	Transparency	CommunicationStakeholder	68	56	-11
	Transparency	EnvironmentallyCertifiedProducts	3	17	14
	Transparency	ProductsSocialStandards	3	15	13
	Transparency	TrasparencyProduction	8	25	17
Environmental Integrity	AirQuality	SlurryStoresCovered	36	15	-21
	AirQuality	ArableLandShareDirectSeeding	17	7	-10
	AirQuality	AccessToPasture	12	0	-12
	AirQuality	SteamingGreenhouse	24		-24
	LandDegradation	WoodlandsDeforestation	60	55	-5
	LandDegradation	ArableLandShareDirectSeeding	55	23	-32
	LandDegradation	SoilDegradationSoilCompaction	79	81	2
	LandDegradation	SoilDegradationCounterMeasures	37	52	15
	LandDegradation	ArableLandErosionControlGreater15Percent	66	64	-1
	LandDegradation	SoilDegradationShareAgricArea	77	78	1
	LandDegradation	SoilImprovement	39	55	15
	LandDegradation	ArableLandGreenCoverGreater30Percent	70	67	-3
	LandDegradation	ArableLandGradientsGreater15Percent	55	33	-22
	LandDegradation	PermanentGrasslandConversion	58	62	3
	LandDegradation	LandslidesMudslides	63	62	-1
	LandDegradation	MeasuresPreventErosion	65	64	-1
	LandDegradation	ShareGreenCoverPerennialCropLand	16	13	-2
	LandDegradation	ErosionPreventionPerennialCrops	65	63	-2

Appendix B7: continued

Dimension	Subtheme	Indicator title	Average RI in percentage		
			Kajiado	Murang'a	(M-K)[1]
			17	7	-11
	AnimalHealth	CleannessLivestockHousing	55	40	-15
	AnimalHealth	AnimalFriendlyHousingSystem	54	42	-12
	AnimalHealth	NumberQualityDrinkingPoints	70	58	-12
	AnimalHealth	DailyOutdoorAccess	30	6	-24
	AnimalHealth	AccessToPasture	28	0	-27
	AnimalHealth	BuyingNewAnimals	41	23	-18
	AnimalHealth	FatteningPigsLosses	55	72	17
	AnimalHealth	PigsQuarantine	43	21	-21
	AnimalHealth	PigletsLosses	41		-41
	FreedomFromStress	ShareDehornedRuminants	41	16	-25
	FreedomFromStress	CleannessLivestockHousing	48	35	-13
	FreedomFromStress	AnimalFriendlyHousingSystem	61	48	-13
	FreedomFromStress	NumberQualityDrinkingPoints	60	50	-10
	FreedomFromStress	DailyOutdoorAccess	37	7	-30
	FreedomFromStress	AccessToPasture	34	1	-34
	FreedomFromStress	LooseHousingSystem	32	22	-10
	FreedomFromStress	BuyingNewAnimals	25	14	-11
	FreedomFromStress	FatteningPigsLosses	53	70	17
	FreedomFromStress	PolishTeethPiglets	45	59	14
	FreedomFromStress	PigletsLosses	39		-39
	FreedomFromStress	MaterialAnimalBusy	29	18	-11
	GeneticDiversity	NumberScatteredFruitTrees	18	44	27
	GeneticDiversity	HybridLivestock	35	49	14

Appendix B7: continued

Dimension	Subtheme	Indicator title	Average RI in percentage		
			Kajiado	Murang'a	(M-K)[1]
	GreenhouseGases	SlurryStoresCovered	32	13	-18
	GreenhouseGases	ArableLandShareDirectSeeding	34	14	-20
	GreenhouseGases	ElectricityConsumption	23	35	12
	GreenhouseGases	DailyOutdoorAccess	16	3	-13
	GreenhouseGases	AccessToPasture	19	0	-19
	GreenhouseGases	PermanentGrasslandMowingFrequency	18	5	-13
	GreenhouseGases	SteamingGreenhouse	14		-14
	WaterWithdrawal	InformationWaterAvailability	34	48	14
	WaterWithdrawal	IrrigationWaterConsumption	62	83	21
	WaterWithdrawal	IrrigationPrecipitationMeasurement	29	49	19
Economic Resilience	FoodQuality	EnvironmentallyCertifiedProducts	5	25	20
	FoodQuality	ProductReturns	38	63	25
	FoodQuality	FoodSafetyStandards	0	11	11
	FoodQuality	DailyOutdoorAccess	31	6	-25
	FoodQuality	AccessToPasture	26	0	-26
	FoodQuality	BuyingNewAnimals	30	17	-13
	FoodSafety	EnvironmentallyCertifiedProducts	4	23	18
	FoodSafety	FoodSafetyStandards	0	12	12
	FoodSafety	TrasparencyProduction	6	19	13
	InternalInvestment	LongTermInvestments	44	56	12
	InternalInvestment	SoilDegradationCounterMeasures	30	43	13
	InternalInvestment	SoilImprovement	26	37	10
	Liquidity	CreditLimit	39	23	-16
	LongRangingInvestment	LongTermInvestments	43	55	11

Appendix B7: continued

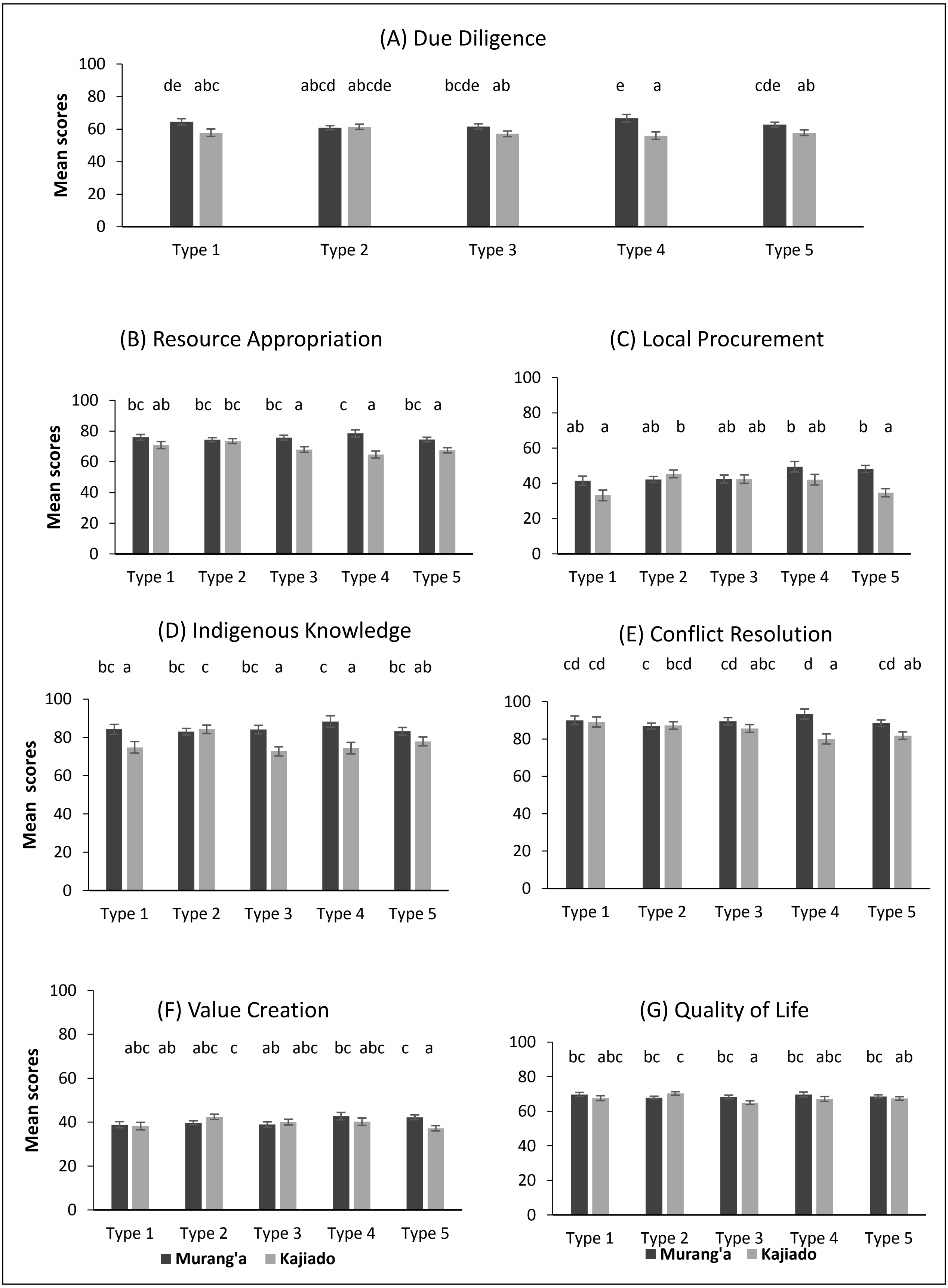
Dimension	Subtheme	Indicator title	Average RI in percentage		
			Kajiado	Murang'a	(M-K)[1]
	LongRangingInvestment	NumberScatteredFruitTrees	15	36	22
	LongRangingInvestment	SoilImprovement	29	40	11
	LongRangingInvestment	LandOwnership	67	78	10
	ProductInformation	EnvironmentallyCertifiedProducts	5	25	20
	ProductInformation	ProductsSocialStandards	5	26	21
	ProductInformation	TrasparencyProduction	8	25	17
	Profitability	ProfessionalAgriculturalAccounts	40	20	-20
	Profitability	MarketChallenges	56	45	-10
	Profitability	NumberScatteredFruitTrees	14	1	-13
	Profitability	FatteningPigsLosses	43	57	14
	Profitability	PigletsLosses	31		-31
	Profitability	SizeMainBusinessUnit	56	70	14
	StabilityOfMarket	ProductReturns	41	69	27
	StabilityOfMarket	LengthCustomerRelationshios	35	55	20
	StabilityOfMarket	TrasparencyProduction	5	17	12
	StabilityOfMarket	NumberScatteredFruitTrees	8	19	12
	StabilityOfProduction	CreditLimit	25	14	-10
	StabilityOfProduction	ArableLandShareDirectSeeding	32	13	-18
	StabilityOfProduction	NumberScatteredFruitTrees	14	34	21
	StabilityOfProduction	HybridLivestock	27	37	10
	StabilityOfProduction	SoilDegradationCounterMeasures	30	42	12
	StabilityOfProduction	SoilImprovement	31	43	12
	StabilityOfProduction	NumberQualityDrinkingPoints	60	50	-10
	StabilityOfProduction	FatteningPigsLosses	39	51	12

Appendix B7: continued

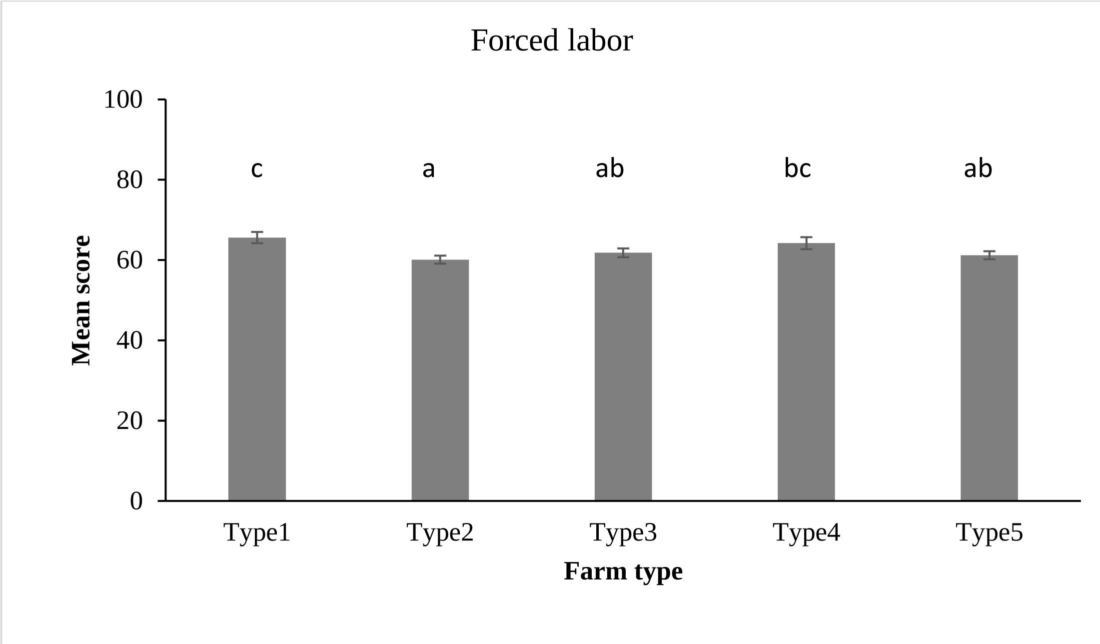
Dimension	Subtheme	Indicator title	**Average RI in percentage**		
			Kajiado	Murang'a	(M-K)[1]
	StabilityOfProduction	PigletsLosses	26		-26
	StabilityOfProduction	NumberPerennialcrops	0	14	13
	StabilityOfProduction	SizeMainBusinessUnit	56	70	14
Social Well-Being	AccessToProductionMeans	PreventionResourceConflicts	47	61	13
	AssociationAndBargainingRight	ProductsSocialStandards	3	16	13
	ChildLabor	ProductsSocialStandards	3	17	14
	FoodSovereignty	LocallyAdaptedLivestockBreeds	60	70	10
	FoodSovereignty	HybridLivestock	41	57	16
	ForcedLabor	ProductsSocialStandards	3	18	15
	IndigenousKnowledge	PreventionResourceConflicts	55	71	16
	WorkplaceSafetyAndHealthProvisions	WasteDisposalPesticidesVeterinaryMedicines	46	57	10
	WorkplaceSafetyAndHealthProvisions	CleannessLivestockHousing	48	35	-13
	WorkplaceSafetyAndHealthProvisions	AccessMedicalCare	49	62	13

[1] *Represents differences in average RI scores between Murang'a (M) and Kajiado (K)*

Appendix B8: Sustainability performance based on interaction of farm types and counties.



Appendix B9: Sustainability performance of farm types in relation to forced labor.



Appendix B10: Details of comparison of sustainability performance of farms based on county, farm type and certification status.

Good governance

For the governance dimension, certified farms performed significantly better than non-certified farms (Figure 3.4A) and farms in Murang'a performed significantly better than those in Kajiado (Figure 3.5A). Multivariate analysis revealed significant certification status and county effects ($p<0.05$) in the subthemes Due Diligence, Holistic Audits, Transparency, Stakeholder Dialogue, Grievance Procedures and Legitimacy, whereby certified farms and farms in Murang'a had higher DGA mean scores than non-certified or Kajiado farms.

In addition, certified farms performed better in the subthemes Mission Statement, Responsibility, Civic Responsibility and Full-Cost Accounting unlike the non-certified farms but there were no significant county difference in these four subthemes. Moreover, farms in Murang'a performed significantly better ($p<0.05$) than those in Kajiado in the subthemes Resource Appropriation, Conflict Resolution, as well as Remedy, Restoration and Prevention. Results of both interaction effects (i.e. county × farm type or county × certification status) reflected this trend of better performance of farms Murang'a than those in Kajiado farms (Table 3.1; Appendix B3).

Environmental integrity

On average, the sustainability performance for Environmental Integrity of farms irrespective of farm type, certification status, and county did not vary extensively with respect to nearly all subthemes except Ecosystem Diversity, which had a DGA between 50% and 69% (Table 3.1, Figures 3.3 to 3.5). Multivariate analyses, however, revealed that organically certified farms performed significantly better than non-certified farms ($p<0.05$) in the subthemes Water Quality, Soil Quality, Ecosystem Diversity, Species Diversity and Genetic Diversity (Table 3.1; Appendix B3).

In addition, farms in Murang'a had significantly lower mean scores than those in Kajiado ($p<0.5$) in the subthemes Greenhouse Gases, Air Quality, Land Degradation, Animal Health and Freedom from Stress. Kajiado farms, however, had significantly lower mean scores ($p<0.001$) for Water Withdrawal and Genetic Diversity than Murang'a (Table 3.1; Figure 3.5B and Appendix B3).

Economic resilience

In the dimension Economic Resilience, organic certified farms and farms in Murang'a performed better than non-certified farms and Kajiado farms, respectively. In both counties, nearly all subthemes had a DGA of above 40% irrespective of farm type, certification status or county, except Community Investment in all cases and Product Information in non-certified farms (Figures 3.3C, 3.4C and 3.5C).

Multivariate analyses results indicated significantly higher DGA ($p<0.05$) for certified farms and farms in Murang'a for the subthemes Long-Ranging Investment, Stability of Market, Liquidity, Food Safety, Product Information than their counterparts. In addition, certified farms scored better in Community Investment and Risk Management than non-certified farms. Furthermore, farms in Murang'a had significantly higher DGA scores ($p<0.05$) in the subthemes Internal Investment, Profitability, Stability of Production, Food Quality, and Local Procurement, but Kajiado farms had higher Stability of Supply (Table 3.1; Appendix B3).

Social well-being

For the dimension Social Well-Being, organic certified and Murang'a farms performed better in general than non-organic and Kajiado farms, respectively. Nonetheless, performance of farms overall was high with a DGA of about 60% and above for all subthemes except Capacity Development (less than 20%) and Support to Vulnerable People (less than 40%) (Figures 3.3D, 3.4D and 3.5D). Multivariate analyses revealed that organic certified farms and farms in Murang'a had significantly higher DGA scores ($p<0.05$) in the subthemes Fair Access to Means of Production, Forced Labor, Child Labor, Freedom of Association and Right to Bargaining as well as Workplace Safety and Health Provisions than their counterparts.

Farms in Murang'a scored significantly better ($p<0.01$) in the subthemes Indigenous Knowledge and Food Sovereignty than those in Kajiado. There were significant interaction effects (i.e. county × farm type × certification status) in the subtheme Forced Labor ($p<0.05$) (Table 3.1; Appendices B3, B4, B8 and B9). Results indicated that non-organic farms (Type 1 and 4) performed significantly better ($p<0.05$) than the organic farms (Types 2, 3 and 5), but among them, certified farms and farms in Murang'a showed better performance compared to non-certified and Kajiado farms irrespective of farm type.

Appendix B11: Indicators responsible for differences in sustainability performance of farms.

Differences in land and crop management

Organic certified farms had limited or no use of agrochemicals and showed better handling of their waste compared to non-certified farms, which improved their performance in subthemes related to soil quality, biodiversity and waste disposal (Table 3.3; Appendix B5).

For the counties results indicated fewer practices to improve soil humus, a lower number of scattered fruit trees and of perennials crops as well as limited measures to improve soil or combat degradation contributed to poorer sustainability performance of the farms in Kajiado compared to those in Murang'a in terms of Genetic Diversity, Internal Investment, Long Ranging Investment, Profitability, Stability of Market and Production, as well as Holistic Audits. For farms in Murang'a, the lower share of land under direct seeding negatively affected sustainability in terms of Stability of Production and Land Degradation (Table 3.4 and Appendix B7).

Farm enterprise

Organic certified farms had significantly more ($p<0.05$) long-term investments in farm infrastructure and land, and more diversified sales and income sources, which contributed to higher sustainability in terms of Long-Ranging Investment, Stability of Market, Profitability, Liquidity and Risk Management than for the non-certified farms. However, significantly high yield losses in certified farms compared to non-certified reduced their Profitability and Stability of Production.

Regarding county differences, the significantly higher ($p<0.05$) commercial viability of the main enterprise on the farm and longer customer relationships in Murang'a contributed to higher economic sustainability in terms of Product Information, Profitability and Stability of Markets compared to Kajiado. Moreover, lower product returns from customers in Murang'a contributed to better performance in terms of Food Quality and Product Information. However, significantly lower levels of credit access and awareness of future market challenges reduced the economic sustainability of Murang'a farms in terms of Liquidity, Stability of Production and Profitability in contrast to Kajiado farms (Tables 3.3 and 3.4; Appendices B5 and B7).

Farmer and employee welfare

Limited support for disadvantaged groups of non-organic certified farms and farms in Murang'a led to poorer sustainability performance in the subthemes Conflict Resolution, Due Diligence, Grievance Procedures, Resource Appropriation, Stakeholder Dialogue, Gender Equality, Quality of Life and Support to Vulnerable People than for the certified and Kajiado farms. In addition, farms in Kajiado had significantly more ($p<0.001$) proactive support for the disadvantaged, but had significantly poorer ($p<0.01$) access to health care than those in Murang'a.

Furthermore, certified farms had more permanently employed workers and workers with social protection than non-certified farms, although the share was very low in both cases, hence sustainability performance was better in terms of Grievance Procedures, Legitimacy, Association and Bargaining Right, Employment Relations and Forced Labor than for the non-certified farms (Tables 3.3, 3.4; Appendices B5 and B6).

In addition, results revealed that certified organic farms had significantly better sustainability performance than their non-certified counterparts ($p<0.001$) in terms of training of farm workers and access to advisory services, which improved their performance in terms of Food Safety, Internal Investment, Long Ranging Investment, Fair Access to Means of Production and Capacity Development (Tables 3.3 and 3.4; Appendices B5 and B7).

Animal husbandry

Animal welfare, in terms of health and freedom from stress was not significantly different ($p > 0.05$) between organic certified and non-certified farms in this study (Table 3.1). However, for the counties, there were major differences in animal husbandry practices. In Murang'a, it was a challenge for smallholder farms to achieve good performance for Animal Welfare due to lack of clean and animal-friendly housing and limited drinking points and outdoor access, dehorning, lack of quarantine areas, limited access to pasture, poor animal slaughter standards, and lack of materials to keep animals busy. In addition, farms in Murang'a had a significantly higher (0.001) level of uncovered slurry stores. However, Kajiado farms reared a significantly lower ($p>0.05$) proportion of livestock compared to farms in Murang'a. This compromised their Profitability, Stability of Production, Animal Health and Freedom from Stress. In Kajiado, limited rearing of hybrid animals reduced sustainability performance in terms of Genetic Diversity, Stability of Production and Food Sovereignty Development (Tables 3.3 and 3.4; Appendices B5 and B7).

Conflicts and land ownership and investment

Results indicate that there were significantly poorer mechanisms to prevent conflicts in the use of resources where ownership was unclear or disputed in farms in Kajiado. This contributed to lower sustainability performance in terms of Fair Access to Means of Production, Conflict Resolution, Due Diligence, Grievance Procedures, Legitimacy, Resource Appropriation, Stakeholder Dialogue, Indigenous Knowledge as well as Remedy, Restoration and Prevention compared to farms in Murang'a. Insecure land tenure in Kajiado affected Long-Ranging Investment (Tables 3.3 and 3.4; Appendices B5 and B7).

Water management

There were no major differences in water management between non-certified and certified farms, although water quality was better in organic certified farms with significantly lower ($p<0.05$) pesticide use and more information on water quality. However, farms in Kajiado had significantly limited information on water availability, used more water for irrigation water annually (per ha) and did not measure the rainwater used for irrigation ($p<0.05$). This led to poorer sustainability performance in terms of Water Withdrawal, Resource Appropriation and Food Safety compared to non-Murang'a (Tables 3.3 and 3.4; Appendices B5 and B7).

Organic certification

Due to a significantly higher share ($p<0.001$) of certified products in the certified farms and farms in Murang'a compared to non-certified farms and Kajiado farms ($p<0.001$), their sustainability performance was enhanced in many subthemes. This contributed to better sustainability performance in terms of Due Diligence, Grievance Procedures, Holistic Audits, Resource Appropriation, Transparency, Food Quality, Food Safety, Product Information, Association and Bargaining Right, Child Labor, Forced Labor (Tables 3.3 and 3.4; Appendices B5 and B7).

Appendix C: Supplementary material for Chapter 4

Appendix C1: Making of litterbags: nylon mesh gas filled with litter/crop residue (maize stover) and field plot where they were buried.

Appendix C2: Pitfall traps in the field with captured arthropods

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