ABUNDANCE, DIVERSITY AND FORAGING ACTIVITIES OF TERMITES UNDER CONVENTIONAL AND ORGANIC FARMING SYSTEMS IN THE CENTRAL HIGHLANDS OF KENYA

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Abundance, diversity and foraging activities of termites under conventional and organic farming systems in the central highlands of Kenya

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DECLARATION

This thesis is my original work and has not been presented for a degree in any other University.

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DEDICATION

This research is dedicated to my family for their support, encouragement and perseverance.

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ABSTRACT

A system comparison (SysCom) program was setup under long-term experiment (LTE) trials to address declining farm productivity due to farm infertilities. The farming systems compared since 2007 were on conventional (Conv) and organic (Org); at High and Low farm input levels; the trials based at Chuka and Thika locations in Kenya. These systems represented a commercial-scale and export-oriented against subsistence productions; receiving maximum vs minimal nutrient and pesticide inputs respectively. A ray of crops were sown firstly over long and into the same plots during short rainy seasons; and so far obtained results showed the potential and advantages of organic over conventional; but with higher presence of termites recorded in trial plots. A further trial over the 2014 to 2015 cropping seasons designed to find reasons discovered farming systems, trial sites, soil profiles and cropping seasons as among key factors significantly ($p < 0.05$) influencing termite abundance by between 1.5 to 5 folds. The Org-High systems receiving natural organic farm inputs, Chuka site endowed with favorable climatic and ideal clay soil content, the uniformly structured top soil profile, and bean-based cropping registered higher termite population. Nine termite genera identified morphologically and grouped into (i) Macrotermitinae (of genera: *Allodontotermes, Ancistrotermes, Macrotermes, Microtermes, Odontotermes* and *Pseudocanthotermes*), (ii) Termitinae (of genera: *Amitermes* and *Cubitermes*) and (iii) Nasutitiermitinae (of genera: *Trinervitermes*) were found in the plots. They belonged and were credited as crop enhancers, foragers, and promoters significantly ($p<0.05$) improving pH, P(Olsen), K, Ca, and Mg chemical elements under Org-High system. Some physicochemical properties, significantly ($p < 0.05$) changed after 7 years of continuous farming included soil fraction by 0.273%, moisture content, and permanent wilting point; which were significantly ($p < 0.05$) changed at Chuka (0.244%) than Thika (0.145%). Similarly soil chemical elements went through significant ($p< 0.05$) changes by up to two-fold; including macronutrients, micronutrients, and exchangeable cations. Also total and castle termite abundance and their foraging activities assessed through tunneling and number of galleries along soil profiles significantly ($p < 0.05$) occurred under the system. The high termite numbers were however further explainable to be significantly ($p>0.05$) and directly affected by soil element the main once being Ca, K, and N and CEC. Further statistical analysis through principal component analysis (PCA) and redundancy analysis (RDA) tools later affirmed these elements to explain some termite genera presence; including *Allodontotermes*, *Ancistrotermes*, *Trinervitermes*, and *Amitermes*. As a crop pest termite activities variably occurred in importance i.e. firstly recorded on dry maize cultivar (grown under Org-Low) and later on baby corn grown under the High (Org- and Conv-) either way causing minimal economical injuries on to the weakly dry maize cultivar seedling, and on to maturing, showing crop senescence baby corn from where high termite population spared vigorously growing by corn seedling. Part of the reason the baby corn seedlings were spared were the presence of the readily available farm inputs that were more preferred as feeds the seedling being spared. In particular the lodging damage by termites were exclusively reported at Thika site, closely associated with *Odontotermes*, *Macrotermes*, and *Pseudacanthoterme* termite genera; as tunneling damage recorded from both the sites closely associated with *Microtermes*, *Amitermes*, and *Ancistrotermes.* Either way the two damage types caused minimal (i.e. below 5%) maize crop damage losses. In conclusion, the possibilities of mass rearing of termites in large population in agricultural fields can be possible and the possibilities manipulating them in agricultural fields to change soil properties and to enhance sustainable crop productivity under Org-High farming systems in the long run exist as an achievement from the study.

CHAPTER ONE

INTRODUCTION

1.1 General background of study

Developing countries in the tropics have been facing challenges with increased food demand against the increasing population growth. Their governments have reacted to this by continuously intensifying farming activities, however, on the same pieces of lands repeatedly divided among family members resulting in minimum productivity repeatedly realized; in a region whose about 75% of rural populations live and regard farming as their main economic activity (Fess and Benedito, 2018).

In Kenya, for example, poorer crop yields continue to be reported resulting sometimes in underfeeding and increased poverty gap (i.e. of about 49.8% being realized by 2012). The increased population growth of about 4% per annum which also is likely to double by 2050 hence requires predictive feeding. The low farm productivity-related to low soil fertility and the inevitable continuous cropping on the same pieces of land has over the decades created concern. In the past traditional farming would be relied on as farmers' practice then adopted long fallowing periods (doing shifting cultivation) since they had large tracks of lands until they restored fertility (ISRIC, 2014).

However, issues related to low land fertility for tropical countries especially towards the end of the last century were found worth being addressed by farming communities from the region who by then started to embrace continuous conventional practices and using limited application of manure and frequently removing of crop residues for livestock feeds and fuel (Sasson, 2018). The conventional farming practices were even further claimed to promote low fertility and negative nutrient balance, resulting in higher erosion, leaching, and inherent soil infertility (Bekunda *et al.*, 2002). The problem from a tropical world was further compounded, the farming practices from there being characterized with mixed smallholder, growers who mainly employed family members to provide labor force. The farmers from the region even indiscriminately use inorganic inputs (i.e. fertilizers and pesticides), aiming at improving soil fertility and control pests with little success continued to be realized thus required research undertaking to be given priority (Gitu, 2004; Bationo *et al.,* 2006). Similar predicaments were previously reported from developed countries. The later successfully reversed this dilemma of low fertility, by resisting exclusive use of inorganic chemical fertilizers and pesticides and instead started to embrace organic farming practices (Mugwe *et al.,* 2009). They mainly opted to practice organized crop rotations, apply manure, and organic fertilizers, and control pests through biological means.

Such farming methodology was later preferred to be extended to the tropical countries, especially after the region showed interest in the enterprise. Organic agriculture which by then was claimed to result in better biological, chemical, and physical soil property changes were then chosen for possible extensions to the tropical region (Mazzoncini *et al.,* 2010; Bationo *et al.*, 2012). It was further claimed farms involved with the practice displayed better and desired crop attribute growth (higher yields) including diversified microbial diversity function (Chen, 1999; Karimi and Naderi, 2007). The multilateral then chose to assess the success of the organic farming system for the highly weathered soils of the tropics aiming to increase farm productivity, improve nutrient cycling, and for soil biological activity (FAO, 1999). The relevance of the “Long-term (LTE) study comparing conventional to organic farming practices was then started to among others: evaluate effects of the farming systems and to generate local relevant field data before its wide adoption. The LTE was then set up at three continents in the warmer global south with chosen countries involved being Kenya (Africa), India (Asia), and Bolivia (Latin America) and the study first commenced in 2007.

1.1.1 Some of the results achieved from the LTE studies

Tangible research results earlier on realized from the Northern hemisphere showed organic practices to be superior to conventional agriculture; performing well in resource use efficiency, ecosystem functioning, soil fertility conservation, and economic performance (Bationo *et al.,* 2012). Farmers involved in the enterprise were also claimed to access attractive markets through certified products apart from creating new partnerships in the value chain, and they displayed strengthened self-confidence and autonomy among themselves (Yussef, 2006; Bationo *et al.,* 2012; Lokos *et al.,* 2018). Such results were both positive and attractive and so instead of transferring results directly to the region; and due to the disparities in climate, soils and socio-economic environments the generation of local data on the subject became a priority. The jointed trials initiated since 2006/7 have been conducted by the Research Institution for Organic Agriculture (FiBL) of Switzerland, in association with icipe, KALRO plus other partners in Kenya. It has been assessing the contribution of organic compared to conventional systems on food security, poverty alleviation, and environmental conservation. The organic agriculture research in particular for the region was then set to be tested for superiority, market accessibility, elevated productivity, and on the extent of improvement of soil physicochemical properties. A number of vital agronomic outcomes have been achieved from the Kenyan trials e.g. the potential and advantages associated with it regarding resource use efficiency, ecosystem functioning, and soil fertility while maintaining a high production level have been realized. That was a promising option for sustainable crop production in the region as observed by Adamtey *et al.,* (2016). On crop protection, various pests and plant diseases were reported from trial plots. It was however, the highly increased termites' population with unknown crop losses associated that remained a concern to stakeholders (Anyango *et al.,* 2019; 2020). Further research on termites was then suggested to be addressed with obtained result content reported here.

Termites are major soil macrofauna whose presence sometimes in high population is known to exist with the richest diversity from especially African continent. Distinct dichotomy literature already exists between the pest management depicting them as agricultural "pests" while another also depicts them for their crucial role in the ecosystems (Verlinden, 2006; Shileshi *et al.*, 2009). As 'pests', termites attack structural timber, rangelands, crops, and trees causing partial or total defoliation with damage associated being severer to older plants and in fields cultivated for longer periods of time (Mitchell, 2002). They have also been described as a major pest to non-native plants and during drier seasons (Ayuke, 2010); to stressed plants depicting higher chemical elements (e.g. of lignin and cellulose) being most preferred (Waliszewska *et al.,* 2019). Other human farming activities resulting in eliminations of termite natural enemies e.g. through natural habitat clearing and burning too are claimed to promote termite pest activities (Black and Okwakol, 1997).

The commonly damaged crops are listed as maize (Zea mays L.), cassava, and even sugarcane causing between 20–30% pre-harvest crop losses in sub-Saharan Africa, affected crops through crop stand loss, wilting and lodging and exposed plants contaminated with soil as they fall to the ground (Van den Berg and Riekert, 2003; Ackerman *et al.,* 2009; Sileshi *et al.,* 2009). Other studies further reported over 90% of the crop damage is attributed to members of the Macrotermitinae family (Abdurahman *et al.,* 2010; Ayuke, 2010).

Although termite species from the family are often associated with crops, they may not necessarily be crop pests, and their high abundance is not necessarily correlated to yield losses as was found by Black and Okwakol, (1997); and Darlington *et al.*, (2008). So far out of the over 3,010 described species worldwide only about 10% of them have been recorded as crop-pests (Ackerman *et al.*, 2009; Sileshi *et al.*, 2009). For example from Sub-Saharan countries, the termite genera listed as damaging to crops have been *Microtermes*, *Ancistrotermes*, *Macrotermes*, *Allodontermes*, *Odontotermes*, and *Pseudacanthotermes* (Munthali *et al.*, 1999; Uys, 2002). Those causing damage to maize have been reported by Sekamatte *et al.*, (2001) and Verlinden *et. al.,* (2006).

In Kenya such termite genera attacking the crops have been reported as occurring more in the low- to mid- altitude, drier areas of eastern, central, and coastal regions as well as in the humid wetter areas of the country (Toft *et al.,* 1992; Ayuke, 2010). According to Wood *et al.*, (1980) and Munthali *et al.,* (1999), the recorded termites attacking maize (*Zea mays* L.) have rarely been reported on maize seedlings but to drying and maturing once commencing from nine to 12 weeks after crop emergence according to Morales-Ramos and Guadalupe, (2001); the damaging termite species living in subterranean nests, from where they attack crops (Gold *et al.,* 1991). As well termites' ecological effects have been stated to happen through their consumption and mineralization of plant and animal materials thus increasing the diversity of vegetation, animal, and microbial communities in agro-ecosystems thus altering soil chemical and physical properties. Termites' presence in soils thus impact significantly on soil pedogenesis, properties, and functions (Ahmad *et al.*, 2006; Govorushko 2019).

1.2 Statement of the problem

After reporting continuous termite presence in the LTE in Kenya, a number of research questions came to bear on the possible reasons making contrasting farming systems to influence termite populations. The possible impacts played by farm inputs, and or the created soil physicochemical property changes on termite abundance became relevant to establish through research. The possible correlation between termite high population and maize crop damage and yield loss was the other area set to be studied.

Hence, a study, superimposed on the ongoing LTE over the 2014 to 2016 cropping seasons were established on these areas of concerns. soil physical changes since 2007 which could have also occurred on soil chemical changes over study periods. The advantage of the farming systems thereby influencing termite population and in return affect agroecosystems in the tropics have been mentioned severally but not receiving the necessary attention (Hendrix *et al.,* 1998; Mando *et al.,* 1999; Quedraogo *et al.,* 2004). Most such research report have however been found through field surveys on termite terminarium (termite hills and nests). No research undertaking have been directed towards agricultural farm situations.

Secondly the importance of termite for its direct or indirect effects on soil properties and in extension affecting the dynamics of soil organic matter have also been mentioned again mainly through field surveys, Hence a side-to-side comparison study was hence set up to as much as possible understand the consequences of farm inputs practices and on the created soil physiochemical properties from different farming systems on termite population dynamics.

1.3 Justification of study

The relationship between high termites abundance to farming systems were deemed as a necessary undertaking especially after repeated high termite in abundance in the LTE were reported. Establishing the reasons associated with certain benefits and other advantages for the termite abundance under contrasting farming systems became a necessity from the current LTE study. The extent by which farm inputs application as human activities effected termite population became a worthwhile undertaking.

Secondly the extent by which the created soil-physicochemical properties similarly reported from isolated field surveys results also became necessary undertaking from the LTE comparison trials before choosing the preferred system for adoption. The targeted physical soil physical properties for study were soil bulkiness, porosities, and infiltration rates. Also the targeted sol chemical properties were the macronutrients, micronutrients, and exchangeable cations. These soil properties are often deemed as important for agroecosystem, hence a clearer understanding on happening following contrasting farming and by extension on termite abundance became a necessity study before clearing any of the farming system for adoption in the tropics. Also since some of the soil chemical properties changes would affect soil nutrients their enhancement by termite indices into farms will be an added advantage and is a knowledge worth establishing.

The relevance of large termite in abundance through the contrasting farming inputs and the possibilities manipulating their abilities to mineralize and decompose organic materials, carbon, and nitrogenous soil contents are worth establishing for sustainable crop production to be enhanced to the tropical region farms firstly at plot level and for posterity (Pascal Jouquet *et al.*, 2021) is another justifiable outcome from the study.

Thirdly, termites' abundance in farms would hopefully be viewed by the project stakeholders and others to not just view them as crop pests worth eradicating always using "hard" pesticides. Their perceptions about termites in agricultural enterprise were hoped to change, them seeing termites as part of a holistic and sustainable farming component as was similarly reported by WHO (2019). The termites' ability in farms would most likely change into them being viewed as farm rescuer, counter-actor of farm degradation whose collapse if occurs through continuous conventional farming its recovery becomes both difficult expensive. This could be a bigger problem to especially the small scale and resource-poor farmers who are the majority in the tropical region (Brussaard *et al.,* 2007; FAO 2017). Farmers' therefore would understand termites' role including enhancement of nutrient cycling, improving soil aeration, porosity, clay matter and organic carbon content change and that definitely is worthwhile outcome and a successful achievements after adoption of the chosen farming systems from among the candidate choices. The selected farming system will hence be viewed as enhancer of soil fauna and as an agent for soil weathering and promotion of fertility, doing so by using residues inputs and other dry matter contents applied to farms.

Through the termite research their pest activities including patterns of damage to maize cultivars would become clearly documented and in a predictive manner; their relevance following reported large population be developed an effective control and management in the region. From other studies termites' pest damaging activities were not directly correlated to termite abundance hence study was justified to among others demystify the notion the high termite abundance in agro-ecological systems directly result in crop attack and yield losses (Quedraogo *et al.,* 2004). The understanding of termites' role on maize cultivars including proper identification of the relevant termite species causing damage that has severally proved challenging as they are cryptic in nature would be accurately predicted.

Such a knowledge was deemed relevant for Kenyans maize farming community who regard maize as a staple crop. The knowledge derived here would be ideal and relevant for the promotion of crop health under large termite population. Finally the study hoped to increase knowledge on the importance of organic farming on plant growth to enhance the full adoption of the chosen farming system that also enhances sustainable and eco-friendly crop production in the region.

1.4 Research hypotheses

1. There is no effect of farm inputs from the farming systems (organic and conventional) on termite abundance, diversity, and damage at the two agro-ecological zones (Thika and Chuka sites).
2. The soil physiochemical characteristics created by the long-term farming systems are not associated with termite abundance and diversity.
3. The termite pest status has no linear effect of termite abundance and diversity and in either farming system (organic and conventional).

1.5. General objective:

To determine the long-term effects (LTE) of conventional and organic farming systems on termite abundance, diversity, and crop damage in Thika and Chuka regions of Kenya.

1.5.1 Specific objectives:

1. To determine LTE from farm inputs under organic and conventional farming systems on termite abundance, diversity, and foraging activities in two agro-ecological zones represented by Thika and Chuka sites in Kenya.
2. To determine the LTE on soil physiochemical changes caused by organic and conventional farming systems and on termite abundance and diversity.
3. To determine termite pest status under different farming systems (organic and conventional) farming systems at Thika and Chuka sites.

CHAPTER TWO

LITERATURE REVIEW

2.1 Overview

This chapter reviews past research on the subject of termites, including systematics and identification, termites' world distribution, the general information about bionomics, biology, and behavior. Others are on termites as human and animal feed, termites for medicinal values, termite population ecology, and their management. The chapter also highlights the effects of farming systems on termite population as would be affected by farm inputs and on some soil physiochemical properties changes. Finally, termite pest activities and some research gaps worth addressing by the current study are highlighted.

2.1.1 General introduction on termites

Termites belong to the order of the Blattodea and have been known to relate closely with cockroaches both having evolved from a common ancestor, until recently, however, the termites were placed under the order Isoptera, a Greek word meaning two pairs of straight wings. Termites have also been called the white ant making their identification for a long time being confused with the true ants. They are now known to be of the sub-order consisting of over 3,106 species worldwide (Granshaw, 2013); their heaviest population areas are in the tropic and sub-tropic regions (Coleman and Wall, 2015). The earliest termite fossil is known in existence dating back to over 130 million years; throughout history. They have been related to destroying structures and invading homes causing damage worth billions of dollars. Termites live in the soil all of their lives and forage for wood constructing mounds, shells and are truly novel insects that are ranked amongst the most successful social pests.

2.1.2 Systematics and identification

Termites are fully social insects, with an extraordinary range of morphological forms living in colonies, with reproductive (kings, queens, and nymphs), soldiers, and “helpers” (true workers and also sexually immature stages assisting within the colony to some extent). These colonies develop around a nest system with division of labor among different castes. Nest systems vary from a single nest concentrated at one site to diffuse networks of subterranean galleries and chambers (Ocko et al., 2019).

The workers are not sexually mature castes and are responsible for nest construction, foraging, caring for eggs, larvae, and royal pairs as well as maintaining the fungus garden (in some families as Macrotermitinae). Moreover, workers feed the larvae, soldiers, and reproductive pairs, which are incapable of feeding by themselves (Eggleton, 2011). They lack compound eyes, do the main work of the colony including the construction of foraging galleries.

Soldiers are the other caste responsible for defending the colony and are characterized by their distinct head capsules from which powerful mandibles enable them to defend the colony against many predators. They are however unable to feed themselves (Tian and Zhou, 2014). Caste ratios depend upon many internal as well as external factors with workers being the most numerous and soldiers lowest in number. Termite morphological and anatomical adaptations are caste-specific, them building structures to provide shelters, fortifications, and climate control thus making them be amongst the most complex social insects their colonies ranging in size from a few hundred individuals to enormous societies with several million individuals.

Termite queens have the longest lifespan of any insect in the world, with some queens reportedly living up to 30 to 50 years. Each individual termite goes through an incomplete metamorphosis that proceeds through the egg, nymph, and adult stages. Colonies are described as super-organisms because the termites form part of a self-regulating entity the colony itself (Bignell, 2011). Communication and social regulation are among the distinguishing features of termites: they are part of all basic aspects of termite biology, from ontogeny and caste differentiation to social behavior and cooperation. As in other highly social taxa, communication in termites predominantly relies on a complex network of chemical signals, which are complemented by vibration-based signals. In contrast to other social taxa, the role of visual cues is negligible.

In lower termites, there are no true workers except for a few species. These individuals are called pseudergates commonly referred to as “workers” and remain immature their entire lifetime. The chemical message which triggers those changes is secreted by soldiers and/or reproductive and spreads throughout the nest due to its volatile nature or is distributed by the termite individuals. It is acknowledged that the level of juvenile hormone (JH) secreted by the corpora allata at molting determines the differentiation into workers and soldiers. Finding that low doses of JH induce the development of workers while high doses trigger soldiers’ development (Yaguchi *et al.,* 2016). In higher termites, the differentiation to any caste is determined before the first molt and appears to depend upon pheromones produced by the reproductive and the soldiers; their developmental pathways differ greatly between different species. At the colony termites frequently groom each other with their mouthparts resulting in attraction among themselves due to the body secretions.

2.1.3 Termites’ world distribution

Termites are widely distributed throughout the tropical and sub-tropical regions, closer to the equator, fewer species live at higher latitudes; mostly being abundant in warmer climates. Some termite species extend their range of occurrence to the relatively cool zones of temperate regions except Antarctica (Bignell, 2019). Termites living within the Asian continent are estimated to be 435 species, Africa, 1000, North America, 50, South America, 400, Europe just about 10 species and Oceania, 360 species.

2.1.4 Termite: Bionomics, Biology, and Behavior

The success of termites can be attributed to their ‘cooperative behavior’ as social insects living in family groups called colonies, in which each termite in the colony performs a specific job that benefits the colony as a whole as opposed to most other insects working only for themselves. For example, in a colony, some members of the caste of termites are responsible for feeding their parents and siblings while others are responsible for reproduction. Because of this division of labor, the colony of individuals functions as a single animal; the different castes interact and communicate as the colony grows (Bagnères and Hanus, 2015).

Often a termite colony starts with swarmers pairing up during their flight, then land and search for a place to begin a family. Their wings break off shortly after landing, and the new king and queen start their colony by excavating a small chamber in a plot of soft soil. When the chamber is large enough, they crawl inside, seal the opening, and mate. From this point on, they will spend the rest of their lives underground. The queen lays her first batch of eggs (6-12) within a few days or weeks of mating. Initially, the king and queen tend the young termites. However, as the queen’s egg-laying capacity increases, the older offspring begin to tend their younger siblings. The colony will now continue to grow with increasing numbers of termites being produced each year. The parental king and queen have the longest life span in the colony. They often survive for a decade or longer and can produce huge colonies with thousands of offspring. The reproductive castle starts at certain times of the year with large numbers of winged swarmers or “alates” reproduced that will eventually become king and queen termites with the latter becoming an egg-laying machine, producing over 10 million offspring a year.

2.1.5 Termites as food

Forty-three (43) termite species are recognized and used as food by humans or are fed to livestock (Fombong and Kinyuru, 2018). They are particularly important in less developed countries where malnutrition is common, as the protein from termites helps in the improvement of the human diet; a practice that has only become popular in developed nations in recent years (de Figueirêdo *et al.,* 2015). In Africa, different tribes have different ways of collecting soldiers of several species (Fombong and Kinyuru, 2018), and although hard to acquire, termite queens are regarded as a delicacy having high levels of fat and protein. In addition to Africa, termites are consumed in local or tribal areas as in Asia and North and South America (de Figueirêdo *et al.,* 2015). Termite mounds are the main sources of soil consumption (geophagy) in many African countries, including Kenya, Tanzania, Zambia, Zimbabwe, and South Africa (Geissler, 2011). Researchers suggest termites are suitable candidates for human consumption and space agriculture, as they are high in protein for humans (Fombong and Kinyuru, 2018).

2.1.6 Termites: medicinal values

Termites also have therapeutic importance in traditional medicine (Jideani and Netshiheni, 2017). Around nine species of termites are known to be used in traditional medicine worldwide, most commonly in Brazil (4 species), India (2 species), Zambia (1 species), Nigeria (1 species), and Somalia (1 species) (Figueiredo *et al.*, 2015). In northeastern Brazil, for example, the termite species Nasutitermes corniger is commonly used in traditional medicine (Alves *et al.,* 2006, 2007) in the treatment of various human diseases like influenza, asthma, bronchitis, whooping cough, sinusitis, tonsillitis, and hoarseness, etc. (Alves, 2009).

Termites can be further used as products with modifying antibiotic activity to aminoglycosides against multidrug-resistant bacteria (Coutinho *et al.,* 2009). The molecular biology and bioinformatics studies on the species from the genus Nausitermes from Australia, showing antifungal and antibacterial activity (Bulmer *et al.,* 2004, 2006). Lamberty *et al.*, (2001) isolated two novel peptides viz., Termicine (antifungal) and Spinigerin (antifungal and antibacterial) from the fungus growing species Pseudocanthotermes spinnger. In the southern part of India, termites (Odontotermes formosanus) are used by many tribes e.g. Kannikaran, Paniyan, Sholaga, Irular, Kota, etc., to treat asthma (Wilsanand, 2005). The Irular and Mudugar tribes have also been using termites for the treatment of rheumatic diseases, body pain, better health, and anemia (Wilsanand *et al.*, 2007).

2.1.7 Termite control measures

Occasionally reported presence and sometimes the outbreak of termites in farms and structures make stakeholders jittery and thus forced to apply control or severally seek expert assistance. The agricultural farmers in particular often look for practices that best fit their economic, and sociocultural conditions with sustainable management methods including a traditional body of knowledge, and practices handed down through generations sorted (Berkes, 2008). They range from chemical, cultural, physical, and more recently, biological measures.

The use of synthetic pesticides began with Chlorinated Hydrocarbons as DDT, aldrin, dieldrin, heptachlor, and chlordane in the 1970s and 1980s. Some of these chemicals were later banned because of their persistence in the environment and accumulation in fatty tissues of animals (Ahmed *et al.*, 2006); thus posing adverse effects to human health (Potter and Hillery, 2002) and so were withdrawn from the market in the late 1980s and early 1990s. These pesticides, by then mainly formulated from emulsifiable concentrates (EC) were replaced with Organophosphates (Ops) based formulations e.g. the Chlorpyrifos that was identified to be more toxic to vertebrates (including humans), but were much less persistent in the environment. This product killed termites' quickly on contact but again also lost their use as the many dead termites near the point of contact with the barrier deterred other termites from the treatment zone and so it was later phased out as a termiticide.

Dozens of synthetic pyrethroids were then identified and synthesized for the purpose of controlling termites the list included fenvalerate, permethrin, cypermethrin, and deltamethrin whose stability and persistence were later improved by chemical compound piperonyl butoxide that increased their effectiveness. Their commercial use quickly faced acceptance as they were highly repellent, thus killing very few termites which avoided the areas where the chemical was applied. Later these pyrethroids were found to be very toxic to fish necessitating precautions to be taken to prevent their use near streams and other surface waters.

Compared with some formulations, the product had less odor associated with it but sometimes triggered asthmatic attacks in persons with respiratory problems. The termiticide Chloronicotinyls, in particular, was introduced for barrier treatment and for the replacement of organophosphates and synthetic pyrethroid products in the late 1990s but was later replaced by Fipronil in the year 2000. The active ingredient popularly sold under the trade names Termidor® and Phantom® were most preferred because termites that were exposed to them died immediately. The other termiticides described as slow-acting stomach poisons of fluoroaliphatic sulfonamides containing sulfluramid included FirstLine® compounds formulated as termite baits. They were sold for termite colony suppression and not necessarily colony elimination. In particular, Subterfuge® (energy production inhibitor) was popularly marketed and preferred in the 2010s.

The insect growth regulators (igr) were another group of termiticide compounds sold to control termites. Their mode of action is to alter insect and termite growth and development. They are much less toxic to humans and other non-target organisms but cause abnormal growth and/or development and either kill the termite outright or prevent it from reproducing. The once marketed for this purpose included Hexaflumuron and noviflumuron (Sentricon®) and diflubenzuron (Exterra® and Advance®). These products are called Chitin Synthesis Inhibitors and they are currently registered for termite control (Su and Scheffrahn, 1998). They are more environmentally friendly and safer for humans and other non-target animals.

Effective cultural methods which help to maintain or enhance plant vigor and which generally are good agricultural practices suppressed termite attacks according to FAO, (2013). The examples are good quality seed, healthy seedlings, and appropriate transplanting procedures or cropping through irrigation practices that help the plants from suffering water stress. Crop rotation according to the FAO, (2013) especially fallow prevents termite attacks. Pruning cuts and accidental wounds treatments in plants with paint or tar or various plant gums help to forestall serious termite infestations. Root pruning of forest seedlings reduces planting shook and enhances and improves post transplanting survival and tolerance to termite attack. Inter-cropping in forests is another means of retaining the range of termite species naturally present and preventing them from achieving pest status (FAO, 2013). The addition and removal of organic matter have both been suggested as methods of reducing termite attack but there is controversy on which of the two leads to reduced termite attack. Weeding practices also reduce termite damage and hoe-weeding, in particular, destroys termite galleries on the soil surface. Artificial breaking up of termite foraging galleries, deep ploughing of soil, and forestry nursery soil beds were later recommended as means of termite damage reduction. High-density sowing and time of harvesting can all be manipulated to reduce termite damage (Terano, 2010).

The Bait formulation termite control was also formulated and is commonly used to suppress termites (Su, 2019). They are edible and attractive substances mixed with a toxicant and impregnated with bait toxicant and registered and acceptable for this purpose under the names: hexaflumuron, diflubenzuron, and noviflumuron. The physical methods of control termites including Quarantine measures and queen removal from ant hills which suppress termites from subsequently becoming pests or prevent further introductions and/or restrict the spread of infestations have also been found effective (Mahapatro and Sreedevi, 2014).

As for Biological control methods, Microbials commencing with Nematodes have been sold for termite control. There is, however, a problem when using nematodes for termite control in fields. In laboratory studies they successfully kill termites however these results have not been replicated in real termite habitats such as in termite-infested home and field crops (Debelo, 2020). . Hence applications of nematodes have not been shown to prevent termite infestations due to lack of their effectiveness under those conditions. The Pathogenic Fungi Metarhizum anisopliae, naturally kills termites and is marketed as a termiticide called BioBlast™. It is applied as a suspension of fungal spore particles that act as a contact termiticide, except the infected termites do not die immediately. It must be applied so that it gets right onto the termites, not just their environment. For the whole colony to become infected and possibly eliminated, this pathogen must be applied to as many termites as possible. The pathogen needs special application and handling techniques and should be stored properly as it will not be effective if tank-mixed with insecticides (Terano, 2010).

2.2 Termite ecology population

2.2.1 Effect of agronomic inputs on termite population

Introduction

The core past knowledge about termite abundance, diversity, and how affected by soil properties have generally been drawn and summarized below from general observations and field surveys often from termite mounds rather than from agricultural farms and systems. Termites also described as social insects live in caste-specific colonies so any slight modification in termite societies are similar to those done to somatic multicellular organisms hence they should then be best thought of as a single organism (or, more controversially, a "superorganism") and defined as an organism, their population variation responding to the well-being of their colonies including shelter, fortifications, and climate changes. Listed below, therefore, are some of the farming-related factors to termite population and foraging activities mainly drawn from research and observations.

2.2.1.1 Cultivation practices

A number of field tillage practices in agricultural farms on termites' populations and diversity were influenced by long-term cultivation practice on the same piece of land which at times promoted their activities. For example, increased mechanical soil disturbances were strongly and negatively correlated to locations of termite nests (Nyagumbo *et al.,* 2015; Ayuke *et al.,* 2019). The no-till, shallow-till, and even fallow systems cultivations enhanced termite species abundance and diversity when compared to the deep-till, the former allowed for more gallery formations with higher termite numbers found. In the reverse frequent cultivation through conventional tilling also negatively affected termite abundance as was observed by Ayuke *et al.,* (2010).

2.2.1.2 Fertility inputs

Effects of fertilizer application, application rates, and time of application on termite population build-up remained uninvestigated. However releases from organic crop residues were found to influence termites' interactions and activities through the created soil microclimate, also depending on litter quality (Bationo *et al.,* 2000; Abdourhamane Touré *et al,* 2011). The effects of organic practices as sources of organic matter generated from manures, straw inputs, soil-composting, and crop type were also positively correlated with termite abundance (Jouquet *et al.,* 2006; Bignell *et al.,* 2011). The residue cover applied as mulch also attracted higher termites with a residue of low nutritional quality quickly consumed than those with high nutritional qualities (Jouquet *et al.,* 2005; Barrios, 2007) Therefore litter quality, soil composting and crop residue types played key roles on termite abundance and diversity resulting in a varied incidence of galleries in the residues (Jouquet *et al.,* 2017). Organic matter application into farms similarly and in a positive manner impacted soil fauna including termites' community resulting in better agricultural soil giving higher crop yields as was reported by Coulibaly *et al.,* (2016).

Other commonly reported observations were about the frequent use of soil of termite mounds for soil amelioration; an observation claimed then to require further research attention (Sileshi *et al.,* 2009; Colloff *et al.,* 2010). Increased termite abundance in combination with agronomic inputs such as mulching and increased water permeability, nutrient and organic matter availability were also reported (Asawalam and Johnson 2007), and even favorable reports from West African farmers concurred termite higher abundance to increase farm values as opposed from East Africa where termites' abundance in any form construed to be agricultural pests and to be controlled using pesticides (Ayuke, 2010).

2.2.1.3 Geographic: (farm location, soil type and climate)

Termite abundance and diversity were still reported from field surveys and observations to depend on geographic location, soil type, and climate variations. In particular clay soils were observed to be responsible for the availability of organic matters which in turn influenced higher termite occurrences and abundance (Bourguignon *et al.*, 2015). The finely divided soil texture under clay soil content was claimed to enhance chemical reactions, plus the fastened release of nutrient elements thus supporting higher termites' population and higher retained soil moisture. The prevailing weather factors under geographical differences including temperature, rainfall, seasonality, and parent geology variability affected termite population and activities. They also positively improved soil drainage and hydraulic conductivity (Ngosong *et al.*, 2015); thus created environments stated to maintain higher macrospores, mixed organic and mineral materials as well as freely allowed termites' movement thus resulting in a nutrient release that positively affected pedogenesis, soil properties and soil functions (Bignell *et al.,* 2006). The higher termite abundance also helped by physically fetching, carrying, and cementing mineral particles into mounds using salivary secretion were the other activities by termites that produced the otherwise poor soils to become healthier and better for plant growth (Lopez-Hernandez *et al.*, 2006; Coulibaly *et al.*, 2016).

Termites' high number in the soil also enhanced soil decomposing, a characteristic that drove their name to be called "soil ecosystem engineer". The termites did so through modification and bioturbation of the physical environment resulting in a highly aerated, with enhanced water infiltration, improved nutrient cycling, and improved agricultural activities as was stated by Baumhardt, (2015). The soil moisture content levels were also controlled by termite behavior, abundance, and distribution along soil profiles them requiring moisture for nests and tunnels building. The moisture was further required for regulating their body temperature and to support feeding young ones (Jouquet *et al.,* 2014).

2.3 Soil physiochemical properties and termite population

2.3.1 Introduction

The research work under this objective similarly relied on field observations reports from termite hills and the contrasted reports with surrounding soils resulting in termite abundance, diversities, and created soil characteristics and not directly from agricultural farms and research. Termites are important soil decomposers and plant nutrients some hardly found to be processed by any other living organism; materials including cellulose and lignin which after processing improved soil quality and promoted termite abundance.

2.3.2 Termites enhancing soil quality

Termite colonies have been described as a formidable agent enhancing soil quality and health; doing so through feeding and foraging activity behavior while searching food, foraging over long distances within soil profiles in many parts of the tropics to agricultural soils (Bignell, 2006; Sileshi *et al.,* 2008). Such enhanced soil quality was stated to be advantageous to farm communities i.e. from Sub-Saharan Africa where the farming community considered farms reporting the presence of termites as more blessed and were often embraced (Coq *et al.,* 2007; Sileshi *et al.,* 2008). To those communities' termites' abilities to consume and mineralize chopped litter, speedy decay crop residues by bacterial and fungal agents; and enriching soil organic matter and mineral nutrients enhanced crop productivity (Freymann *et al.,* 2008).

The general belief, therefore, were termites as being beneficial organisms for functioning farming ecosystems and should be advocated for their presence which should be appreciated rather than condemned; however without any tangible research findings to back the belief (Jouquet *et al.,* 2011). They further noted termites' large presence in farms as requiring concerted management research undertakings. It was further believed termites contributed to the consumption and mineralization of litter through mechanical means chopping them up and speeding up the decaying processes by bacterial and fungal agents. Such soils ended up being enriched with organic matter and mineral nutrients and through feces, salivary secretions, and corpses when they died (Bignell, 2006, 2011; Sileshi *et al.,* 2008; Mujinya *et al.,* 2010; Jouquet *et al.,* 2011). Termites also had the ability to alter soil physical properties through loosening soil particles, thus reducing soil bulk density both under vertical and horizontal soil profiles through bioturbation (Jouquet *et al.,* 2011). Also, termites' ability to control their own living environment including the humidity and temperature levels qualified them in farms as soil ecosystem engineers (Jouquet *et al.,* 2011).

2.3.3 Mineral salts and termites

Some other observations about the termites' higher abundance revealed further ability to increase mineral chemical content, including those of carbon, organic matter, exchangeable Ca, Mg, K, and Na contents observations commonly noted from termite mounds when compared to surrounding soils (Bignell *et al.,* 2006; Brossard *et al.*, 2007). Similarly, termites severally mineralized soil organic matter to ammonia and nitrate and to contribute to higher soil N dynamics (Masunga 2016); in reverse, some chemicals as nitrogen and phosphorus) were reported as lowered (Momah *et al.,* 2018).

2.3.4 Enhanced organic matter and nutrients with increasing termite population

Enhanced plant nutrients, hydraulic conductivity, improved water, and air infiltration rates were also recorded within termite mounds when compared to surrounding soils; despite their effects on especially agricultural production not being understood until recently (Holdo and McDowell, 2004; Sileshi *et al.,* 2009). A direct link, therefore, existed between higher crop yields and termite occurrence in abundance, on soil stability for micro aggregates, for the increased soil porosity and enriched soil organic matter (Pardeshi and Prusty, 2010; Millogo *et al.,* 2011). From those studies, the encountered organic matter impact i.e. positively enhanced soil stability and biogeochemical cycling of nutrients contributed to better crop development which was still poorly known in agricultural systems (Karhu *et al.*, 2011; Schowalter, 2016).

2.4. Damaging termite pest

This part of the study endeavored to establish the extent to which termites' pest status on maize relative to their large numbers and effect on yields from past literature. Termites' extent and patterns of damage including injury symptoms as well as termite species involved are highlighted.

2.4.2 Termite damage to crop

Like any insect pests, termites feeding activities are reported to cause damage to crops. Due to their cryptic nature, the description of the extent of the damage it caused also remained unclear i.e. only being realized well after it had occurred. The same would be stated for termite species responsible for the damage thus making the identification exercise to become equally challenging (Lenz *et al.,* 2003). The encountered termite species in farms have also been found to have greater appetite feeding and damaging all sorts of crops on their foraging line causing between 3–100% crop losses in Africa (Mitchell 2002; Mugerwa *et al.,* 2011). The majority of the termite species associated with crops, however, could not be considered as crop pests i.e. not correlating with yield losses, and some notable damage symptoms associated with termite damage to maize crops have been described as partial or total defoliation, mostly related to wilting and lodging (Loko et al., 2017). Such injured crops by the termites in the fields were further later exposed to other damage by rodents and fungal contamination (Sekamatte and Okwakol, 2007; Riekert and Van den Berg, 2003). Also, termite mounds often built by the termites in farms at times disrupted farming activities, e.g. making farm machinery operation difficult, however without any production statistical losses presented (Capinera, 2008). The termites' damage to buildings was yet the other recognized severe damage by termites (Ugbomeh and Diboyesuku, 2019).

2.4.3 Identity of the damaging termite

The identity of exact termite species considered to be most problematic had always attracted taxonomic studies with little success reported due mainly to the difficult cryptic nature of the pest (Narayanan, and Thomas, 2016; Kumari *et al.*, 2013). The following feeding groups have however been classified and described: i.e. a) Feeding group I: that feed on wood, litter, and grass feeders (lower termites), b) feeding group II: that feed on wood, litter, and grass feeders (some of the higher termites), c) feeding group III: that feed on very decayed wood or high organic content soil (all higher termites), and d) feeding group IV: that feed on low organic content soil (true soil-feeders-all higher termites). To the agriculturalists was the feeding groups I and II that had been of particular importance; them seeing that group as crop pests (Ayuke, 2010; Costa-Leonardo and Haifig, 2014).

The damaging termite species to maize crops have generally been described as belonging to the genus: *Macrotermes, Odontotermes, Pseudocanthotermes, Ancistrotermes,* and *Microtermes* (Toft *et al.*, 1992). They mostly belonged to the sub-family Macrotermitinae whose control in farms exceeded $20 billion annually worldwide (Jouquet *et al.*, 2017; Govorushko, 2018).

CHAPTER THREE

MATERIALS AND METHODS

3.1 Overview

This chapter describes the materials and methods used in executing the experiments on termites and farming systems. Briefly the materials included field sites, farm inputs (e.g. the grown crops, various nutrients and pesticides, and farm tools). Similarly the methodology employed were: the trial field preparations, treatment arrangements, field layout, and designs. As well the procedures to conduct trials including data sampling, data collection, data handling, data management, and data analysis are described below. The weather factors over the trial period are highlighted.

3.2 Materials

3.2.1 Field sites

The study on the effect of the farming systems on termites was conducted between March 2014 and September 2016; superimposed on the ongoing Long-term Farming Systems Comparisons (SysCom) trials situated in the sub-humid zones of the Central Highlands of Kenya at Chuka (Tharaka Nithi County) and located at longitude 037° 38.792' N and Latitude 00° 20.864' S) at Kiereni primary school garden. A parallel study was also conducted at Thika (Murang'a County), located at longitude 037° 04.747' N and latitude 01° 00.231' S) at KALRO-Kandara research ground. These sites are 150 and 40 Km North of Nairobi and lie in the upper midland 2 (UM^2) and upper midland 3 (UM^3) agro-ecological zones respectively (Jaetzold *et al*, 2006); also known individually as main coffee and sunflower-maize growing zones respectively. They stand respectively at an elevation of approximately 1458 and 1500 m above sea levels; areas characterized by a bimodal rainfall pattern (long rainy and first cropping from March to June and secondly short cropping from October to December) receiving a mean annual rainfall of 1500 mm at Chuka and 900-1100 mm at Thika sites. The mean annual temperature ranges were usually from 19.2 – 20.6 °C at Chuka and 19.5 - 20.7°C at Thika. Whereas historically Chuka soil was derived from Humic Nitisols, the Thika soils were derived from Rhodic Nitisols - based on the FAO world reference (IUSS Working Group WRB., 2006; Wagate *et al.*, 2010 a, b). The study sites were located at the sites characterized by a medium to long first cropping season and a medium to a short second season with a yield potential of very good to fair according to Jaetzold and Schmidt, (1983). The soils at the sites were highly weathered, characterized by low soil nutrients including cation exchange capacity, base saturation, and exchangeable aluminum saturation (see the summary about the sites Table 3.1 and Figure 3.1).

Table 3.1: Summary of sites characteristics at Chuka and Thika, Central Highlands of Kenya

	Units	Chuka	Thika
GPS		37°38.792‘ N 0°20.864‘ S	37°04.747‘ N 1°0.231‘ S
Altitude	m a.s.l.	1‘458	1‘500
Mean Annual Temperature	°C	19.2 – 20.6	19.5 – 20.7
Mean Annual Rainfall	Mm	1373 (bimodal)	840 (bimodal)
A\groecological Zone		UM $_2$ (Main Coffee Zone)	UM $_3$ (Sunflower-Maize Zone)
Soil classification[a]		Humic Nitisols	Rhodic Nitisols

[a] based on FAO world reference base for soil resources (IUSS Working Group 2006, Wagate, Njoroge et al. 2010a, Wagate, Njoroge et al. 2010b)

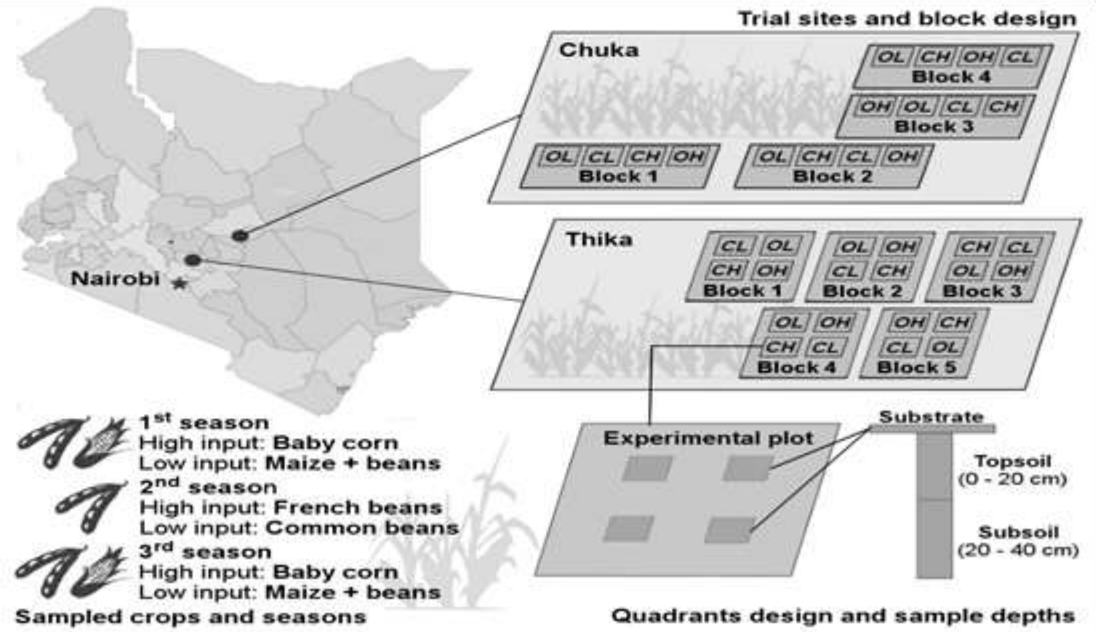


Figure 3.1: Location, crops and experimental design of the termite study in the farming systems comparisons trials at Chuka and Thika, Central Highlands of Kenya

3.2.2 The general description of farm inputs

3.2.2.1 For the LTE trials: Historical aspects

The Long-Term Experiments (LTE) were firstly officially established in early 2007 aimed at comparing conventional (C) and organic (O) farming systems. The systems were further compared under two nutrient levels i.e. Low and High (Table 3.2). The conventional or organic high input system (Conv High or Org High) represented the situation of commercial growers; as the conventional or organic low input systems (Conv Low or Org Low) represented small scale snd crops grown for domestic and local marketing. The farm inputs to grow crops under farming systems are detailed under Table 3.2.

3.2.2.2 Treatments towards LTE trials

The trial plots measuring 8 x 8 m (with an inner net plot size of 6 x 6 m) were used for data collection and the treatments applied into the Randomized Complete Block Design replicated four and five times at Chuka and Thika, respectively (Figure 3.1).

Table 3.2: Input details for the long-term experiments at Chuka and Thika in Kenya

Farming system	Farm inputs	Farming type
CONV LOW	Organic & synthetic fertilizers, pesticides, limited rates (costs) (45kg N/69 kg P2O5/ha/year)	Small scale, Home consumption and local market
ORG LOW	Low organic inputs, no plant protection, limited rates (costs) (45kg N / 69 kg P2O5/ha / year)	Small scale, Home consumption and local market (no premium prices)
CONV HIGH	Organic & synthetic fertilizers, pesticides, irrigation*, rates as recommended (225kg N / 286 kg P2O5 ha/ year)	Commercial, Urban domestic and export market
ORG HIGH	Organic, rock-phosphate, bio-pesticides**, irrigation*, rates as recommended (225kg N /286 kg P2O5/ ha/ year)	Commercial, Urban domestic and export market (premium prices)

* Irrigation was introduced in 2008 second season; Bio-pesticides e.g. neem (Azadirachta indica) oil extract, Thuricide (Bacillus Thuringiensis v. Kurstaki) , Achook (Azadirachta indica) + Dipel (Bacillus Thuringiensis v. Kurstaki), Delfin (Bacillus Thuringiensis) + Fungi icipe isolate 30 (Metarhizium anisopliae or Metchnikoff Sorokin)

Table 3.3: Treatments under LTE trial sites (Chuka and Thika)

System	Approach	Fertility management.	N (kg ha^{-1})	P (kg ha^{-1})	Pest &Disease management
Conv-Low	Small-scale, home consumption and local market	Organic & synthetic fertilizer	45	60	Synthetic pesticides
Org-Low		Organic fertilizer	45	60	Bio-Pesticides
Conv-High	Commercial, domestic and export markets	Organic & synthetic fertilizer	225	286	Synthetic pesticides
Org-High		Organic fertilizer	225	286	Bio-Pesticides

3.2.2.3 Cropping into the trials

3.2.2.3.1 Crops grown under the LTE

The selection of the crops to be used into the LTE, and for the crop rotations were heavily drawn based on farming community practices close by trial sites, and from reports by Musyoka, *et al,* (2007); as well as recommendations by Székely and Wang, (2005). The chosen crops to be used in the trials were further borrowed from recommendations by the Kenya Institute of Organic Farming (KIOF). Hence the chosen crops to the LTE included cereals, vegetables, legumes, and a tuber; the plants established into a 6-season-3-year crop rotation whose details' are displayed pictorially Plate 3.1 and further shown on Table 3.4 that shows the crops details for the first three years.

Plate 3.1: Pictorial display cropping pattern and rotations over the 6-season-3-year rotation since 2007

Table 3.4: Crop diversity and cropping pattern of the long-term systems comparison trials over the long term (LS) and short term (SS) seasons at (Chuka and Thika) sites Central highlands of Kenya.

Farming System	**LS****	**SS*****	**LS**	**SS**	**LS**	**SS**
	Year 1*		**Year2**		**Year 3**	
CONV LOW	Maize	Kales/ Swiss chard	Maize/ dry beans	Dry beans	Maize	Potato
ORG LOW	Maize	Kales/ Swiss chard	Maize/ dry beans	Dry beans	Maize	Potato
CONV HIGH	Maize/ Mucuna**	Cabbage	Baby corn/ Mucuna	French beans	Baby corn	Potatoes
ORG HIGH	Maize/ Mucuna**	Cabbage	Baby corn/ Mucuna	French beans	Baby corn	Potatoes

* Year 1: Commencement of the trials in 2007; ** LS - Long rains season, ***SS - Short rains season; Mucuna planted as relay crop 4 weeks after maize or baby corn establishment; Mucuna biomass was applied in the short season to the proceeding crops in addition to other crop residues

3.2.2.3.2 Cropping sequencing over termite research work (2014 and 2015)

The crop selection for the high input systems (Conv High and Org High) over termite research research involved baby corn maize cultivars. That to be used into low input systems (Conv Low and Org Low) also involved usage of dry-maize cultivar sown twice as the dominant cereal crops in the long seasons (2014 I and 2015 I). The second crop into high system over second season were on the other hand the French beans and the dry beans into the low input plots over the second and short season in 2014 II.

The baby corn cultivar grown for over termite research period were of variety Pannar 14, and the dry maize of variety H513. Whereas the baby corn were grown as a pure stand, the dry maize on their part were sown as a mixed stand supported by dry bean (*Phaseolus vulgaris*) of variety GLP 92 with dry maize (variety H513), (Muir and Foster, 2011) planted into low input plots (organic and conventional). The French beans (var *Kirengeti*) was the other second bean crop planted into the trial into the high system plots and during the 2nd season cropping (September to January) (see details Table 3.4).

3.2.3 Treatment towards plant nutrients and termite control

Since 2007 the LTE was designed to achieve per year the listed (summarized amount of nutrients materials) Table 3.3, biased towards conventional and organic systems. Towards the conventional inputs embraced the purchased agrochemicals such as inorganic mineral fertilizers such as TSP/DAP and CAN, and to the organic systems plant nutrients received through the natural organic inputs including composted soil, green manure and plant extract, and bits of plant residue and mulches. In addition, the organic inputs included indigenous concoctions made from starter liquid and chopped *Tithonia* leaves, dry grass mulch, *mucuna* stover mulch, and the planted Mucuna as green cover crops.

The crops were further protected from arthropod pests and plant diseases by applying the purchased agrochemical pesticides listed Table 3.5. and some formulated through concoctions. To the conventional plots inorganic gladiator (Chloropyrifos 20EC) and organic plots were singly applied icipe 16 to control termites. The comparison experiment towards the farming systems and which formed the core management treatments on termite were named as follows: (i). Conventional lows where soil nutrients were supplied through inorganic fertilizers at an average rate of 50 kgNha-1 yr-1; (ii). Conventional high where plant nutrients were supplied through inorganic fertilizers at average rate 225 kgNha-1 yr-1; (iii). Organic low where soil nutrients were supplied through raw cow manure and low amount of phosphate rock (PR) and, (iv). Organic high where soil nutrients were supplied through soil compost, liquid manure from *Tithonia diversifolia*, various crop residues such as mulch (maize stover, dry grass, *Tithonia*); and besides these were a legume crop (*Mucuna pruriens*) planted as inter- cover- crop; and to plots were further occasionally supplied with metered irrigation during dry spell as suggested by IFOAM, (2008). Further assorted pest management designed to specifically control termites were: to (i). under Conventional low using inorganic pesticides (gladiator – Chloropyrifos) at half the recommended rates; (ii). To conventional high where termite pests were controlled using the recommended rates Choropyrifos, (iii). Organic low where termites were controlled through farmers' concoctions or even left unsprayed; and (iv). Organic high where termites were controlled through the commercially recommended botanicals and the biopesticide icipe 16 Table 3.5.

Table 3.5: Input details for the long-term experiments and farming type at Chuka and Thika in Kenya.

Farming system	Farm inputs	Farming type
CONV LOW	Organic & synthetic fertilizers, pesticides, limited rates (costs) (45kg N/69 kg P2O5/ha/year)	Small scale, Home consumption and local market
CONV HIGH	Organic & synthetic fertilizers, pesticides, irrigation*, rates as recommended (225kg N / 286 kg P2O5 ha/ year)	Commercial, Urban domestic and export market
ORG LOW	Own organic inputs, no plant protection, limited rates (costs) (45kg N / 69 kg P2O5/ha / year)	Small scale, Home consumption and local market (no premium prices)
ORG HIGH	Organic, rock-phosphate, bio-pesticides**, irrigation*, rates as recommended (225kg N /286 kg P2O5/ ha/ year)	Commercial, Urban domestic and export market (premium prices)

* Irrigation was introduced in 2008 second season; Bio-pesticides e.g. neem (Azadirachta indica) oil extract, Thuricide (Bacillus Thuringiensis v. Kurstaki) , Achook (Azadirachta indica) + Dipel (Bacillus Thuringiensis v. Kurstaki), Delfin (Bacillus Thuringiensis) + Fungi icipe isolate 30 (Metarhizium anisopliae or Metchnikoff Sorokin)

3.3 Methodologies

3.3.1 Field trial operation details

3.3.1.1 Land preparations and sowing

Planting of the crops to the designated LTE plots was done after uniform land preparation using hand hoe working it into a fine tilth over 2014 I and 2015 I cropping seasons. The crops planted then were baby corn sown as mono-crop into high input plots (organic and conventional) and as dry maize (variety H513) planted as an intercrop with beans (variety GLP 92) into low input plots (i.e. organic and conventional).

The second crops planted at the sites in September 2014 were French beans (var

Kirengeti) into high input plots and dry beans (*Phaseolus vulgaris* var. GLP 92) into low input plots (see Appendix 1 and as graphically presented in Figure 3.1). After crop emergence weeding were twice done using a hand hoe through the recommended husbandry (Muriuki and Queresh, 2001). The baby corn spaced 75 cm between rows and 30 cm between plants with one seed per hole and dry maize planted as intercrop of one row of maize alternated with a row of common beans at a space 75 cm between rows and 60 cm between maize and 30 cm between bean plants (two seeds per hole). As much as possible planting occurred within the same week at the two sites (Chuka and Thika).

3.3.1.2 Fields layout and treatments

These farming systems formed the core treatments under the comparison farming systems. The experiments were laid out, and replicated four times in Chuka and five times in Thika (details graphical presentation Figure 3.1. The figure further summarized field layout detailing crops grown over the three cropping seasons).

3.3.3 Procedures for conducting termite studies against the set objectives

3.3.3.1 Sampling termites population against farm inputs

Termite indices understudies (i.e. abundance and diversity) were assessed against the influence of farm inputs through weekly termite sampling. These values were sampled weekly every cropping season as from week 1 since crop emergence (WAE) to last harvesting day. The sampled parameters were from within the net experimental plot at 4 quadrants within the 6 x 6 m^2. In the sequence of sampling it will firstly involve checking for the presence of termites from within residue/ litter, an area 1 x 1 m^2 (i.e. 100 x 100 cm^2 repeated 4 times per plot. Further sampling involved from below ground, sampling a soil core 10 x 10 cm and a soil depth 10 cm, again repeated 4 per plot (Plate 3.1). The sampled soil cores were then quickly placed onto a polythene sheet using a spade, an operation repeated from 4 layers (namely 0-10, 10-20, 20-30, and 30-40 cm soil depth) along soil profiles. The sampled termites were then sorted, counted, and preserved into labeled bottle vials containing a 70% absolute alcohol. The other samples were further preserved into absolute ethyl alcohol, the whole sampling process repeated 7 other times from within rows and between plant rows per plot. The encountered total and castle termites were further counted and recorded, bottle jars labeled and relevant pieces of information inserted such as date of sampling, sites, plot number, crop phonology, and weather conditions. The sampled termites' soldiers were further subjected to morphological identifications using hand lens and later confirmed at Nairobi National Museum using the standard determination keys by Webb, (1961) and Sekamatte, (2001) and termite population per plot scored into spreadsheets.

3.3.3.2 Sampling termites population against soil physiochemical properties

The termite indices were compared against soil physical and chemical properties; a study conducted at KALRO-NARL. The soil physical characters determined once over the trial period included bulkiness, soil texture, porosity, hydraulic conductivity, saturations, and wilting points. Such soil samples were done from both the disturbed and undisturbed portions of the plots. Disturbing soil portion entailed scrapping carefully to get to lower layers of topsoil (0 – 20 cm); then the subsoil (at 20 - 40 cm deep). From there, soil sampling using steel cylindrical cores of 100 cm3 volume (5 cm in diameter, and 5.1 cm in height) was employed. A parallel wetted plot portion for 24 hours were similarly sampled using the same equipment. The sampled soil were then bagged and labeled following the descriptions by Blake and Hartge, (1986). At the laboratory (i) bulk density megagrams per cubic meter (mg/m3) were assessed after oven-drying the sampled soils at 105^{o}C, then sieving through an 8 mm. The sieving exercise involved gently breaking down soil clods (Cresswell and Hamilton, 2002). ii). Hydraulic conductivity measurements were the other physical property sampled for, conducted through an equilibrium, the quantity of water, Q (m3) flowing out of the sample of length, L (m), and cross-sectional area, A (m2). The outcome gave the hydraulic-head drop, Δh, and time elapsed, t (s) which after calculations resulted in hydraulic conductivity ($K\theta$), also called Darcy's equation. iii). Soil water retention curves were yet the third soil physical factor sampled to characterize soil moisture saturation. This was done through methodologies by Wind (1968). iv). The wilting point (permanent wilting point) was the other factor determined. It was conducted through the retention curve method after submitting soil samples to different tensions in the Richards Extractor using a methodology by Long *et al.,* (2003). And v) soil stability (soil texture) was another physical factor measured doing so using the Hydrometer method with values calculated after dispersing soil particles with sodium metaphosphate (Calgon) then sieved through 8, 4, 2, 1, and 0.5 mm wet-sieve apparatus, the latter separating soils into sand, clay and silt aggregates (Hinga *et al.,* 1980; Kemper and Rosenau, 1986). These results on the physical factors were finally recorded in triplicates per plot before analysis.

Soil chemical elements sampling were also conducted at three randomly chosen sites per plot. They were conducted at soil depths 0–20 cm after after air drying on nonmetallic trays. At the laboratory the sampled soils were then sieved through a 2mm sieve' then the resultants were assessed for the soil elements including the macronutrients, micronutrients, and exchangeable cations (e.g. pH, C%, N, K, Mg, Ca, Na, P, S, and Mn) (Hinga *et al.,* 1980; Haney *et al.,* 2006). For example, sampled soils for (i) pH and EC content were determined with an MP521 pH/EC meter for a slurry consisting of 1:5 (W/V) soil/distilled water (McLean, 1982) using Beckman Zeromatic pH meter. ii). Soil organic carbon (OC%) content was measured by the potassium dichromate wet-combustion method. iii). The percent organic matter was calculated by multiplying C% values by the "Van Benmelin" factor - 1.724 (Zhang *et al.,* 2013); also described by Nelson and Sommers, (1996). iv). The CEC is determined through the calculation of all exchangeable cations (Olsen and Sommers, 1982). v) The soluble Na^+ and K^+ were determined with a flame photometer after NH4OAc neutral extraction (Page et al., 1982). vi). The Ca^{2+} and Mg^{2+} were determined by titration with EDT A (Jackson, 1962). vii). And available N was determined through a macro- Kjeldahl digestion method (Blackmon, 1971) and distilled using NaOH to give water-soluble, organic nitrogen (N%).

The extent to which termites in abundance and diversity would be affected by soil physicochemical properties were determined through a bi-weekly termite sampling and by using counts data. They strictly used termite indices (abundance and diversity) collected on the 15th and 30th day per month or close-by dates. Also, termite foraging activities within soil profile were determined every quadrant of the plot through (i) the length of tunneled top soil surfaces and at substrate from an area of 10,000 cm^2 area per plot. The number of pocked holes/ and galleries from within 1,000 cm^3 soil volume gave details of termite movements at top- compared to sub-soils measured in numbers for the farming system and sites.

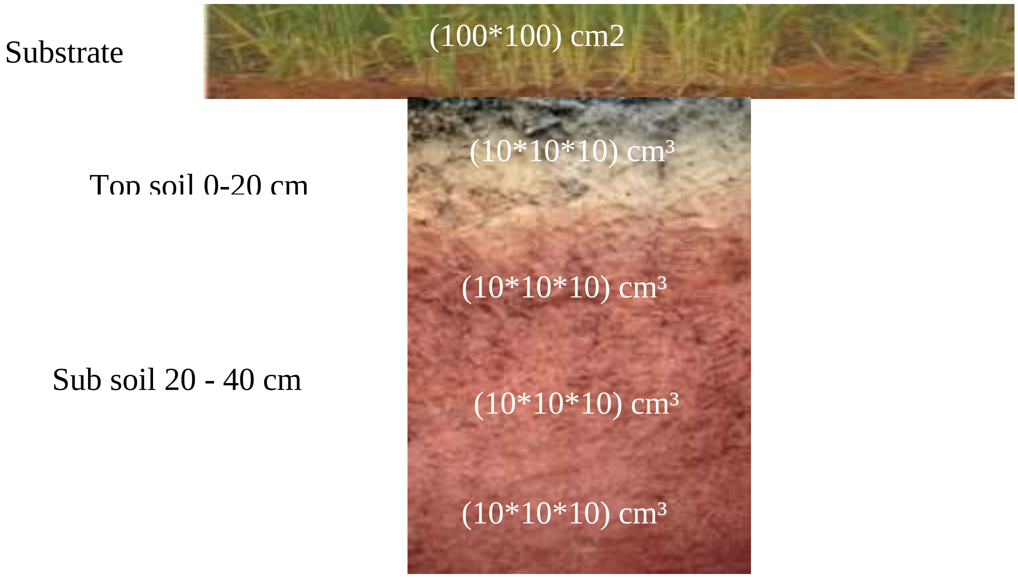


Plate 3.2: Soil profiles from where termite samples were taken

3.3.3.3 Sampling termites population against termite pest activities

Studies on termites' pest activities causing damage to maize crops commenced from 1st week since crop emergence. The damage type, injury patterns, and extent of damage to crop along crop phenology were assessed distinguishable under lodging, tunneling, and "earthing". The lodging damage entailed from a quadrant of a plot by randomly choosing 10 plants and those found as cut by termites and fallen to ground considered to have been lodged according to the methodology by (UNEP, 2000), and illustrated here by Figure 3.2a. The methodology so far were non-destructive with counted and scored plants found to have had a clean cut at the stem-base and lodged off repeatedly counted weekly from 1st to the 20th week after emergence (WAE). The chopped plants tally also combined those chopped and later found to dry-up per plots as were sometimes supported by other plants within the plot. The total lodged plants were then expressed as relative total plant population per quadrant then scored into the datasheet after multiplying by four against the crop phenology as shown (Appendix VI).

Tunneling crop damage was the other sampling scored, the results based on the number of tunneled plants per plot. Such a sampling was conducted through a destructive type i.e. uprooting and examining twelve plants per plot using a hand hoe; a sampling that was done once at the end of the trials the uprooted plants individually dissected physically checking for the number of plants exhibiting perforations and soil inside themselves counted and scored. Before scoring however tunneling damage were confirmed tunned after checking for termite entry points at the roots termites extended foraging excavating maize stem from inside, taking keen care revealing damaged and mature plants at times tunneled but remained intact and even hallowed filled with a mixture of soil, feces, and soil-particles also added to the tally expressed as a percentage per plot. Finally, sampling for “earthling damage” which was eventually established as termites' ability to construct pass way shelters on plant tissues using mud was initiated and done under the current study but for only 1st season trial then later discontinued thereafter. It was only on the realization the so called “damaged” plants cleared off by any slightest movement plant tissues by farm-workers and showers, the damaged plant tissues later clearing off becoming blemish less. Lastly, termite-genera/ species found to be associated and could be responsible for damage symptoms (lodging and tunneling) were weekly sampled. Their correct identification through molecular studies at icipe using methodologies by Abdurahman, (1990) and Sileshi *et al.*, (2010).

3.3.4 Data collection and management

At the end of sampling, over 24,400 data sets on termite total abundance, termite castes, termite genera, termite activities scores were entered and validated after checking for any double or missing entries into a database (Appendix 4). Other descriptive information gathered from general observation was also validated and largely used to answer study objectives aimed at obtaining information about farming systems, trial sites, seasons, blocks and plot numbers, quadrant numbers and sampling depths effects.

3.3.4.1 Data analysis for termite population (abundance and diversity)

The data on termite numbers were used to calculate termite average numbers and incidence per quadrant expressed as; a) the presence of termites (abundance > 0) = 1, and b) the absence of termites (abundance = 0) = 0. Afterward, all data on termite abundance and incidence per quadrant were summarized for each plot (at substrate an area of 10,000 cm2; and at soil depth soil volume 4'000 cm3). The incidence data were then calculated as an incidence index ranging from 0 to 4 (0 % presence to 100% presence in each plot). Data on termite abundance again were analyzed with a linear mixed effect model to determine the significant effects of the fixed factors using the lmer function from the lme4 package (Bates *et al.*, 2015). The model included 3 or 4 fixed factors: farming systems, cropping season, trial site, and sampling depth (only for data relating to the top and subsoil) and their interactions, and one random factor (field replication - block). Computation of the estimated marginal means were done using the emmeans package (Lenth, 2017), followed by mean separation using the adjusted Tukey's method using the multicompView package for cld function (Pierpho, 2004). The results were largely expressed graphically through histogram and descriptive analysis significance level for all tests were $\alpha = 0.05$. And to characterize the diversity of termite (soldier) genera a software EstimateS were used (Colwell, 2013) to determine species richness (S), the incidence-based coverage estimator of species richness (ICE), the Chao2 estimator of species richness, the Shannon index (Sh) and inverse Simpson index (Si) as diversity measures. Data sets were separated by sample depths prior to statistical analysis.

3.3.4.2 Data analysis on effect of soil physiochemical characteristics

Data on soil characteristics and of termites were also subjected to analysis of variance (ANOVA) following procedures for CBD under the variables; (i) total termite abundance/incidence, and (ii) termite taxa density. The collected data were subjected to Levene's test to assess homogeneity by square root transformation (x + 0.5)1/2 (Field, 2009). The data levels of difference significances were evaluated using Fisher's least significant difference (LSD). Secondly, a linear ordination technique Redundancy Analysis (RDA) was used to investigate the correlative relationships of soil factors (6 physical and 13 chemical) with termite abundance. The lowest taxonomic level which was confined at the generic level were also evaluated through the linear ordination technique Redundancy Analysis (RDA). RDA was tested for statistical significance differences at $P < 0.05$. The first variable selected was of the highest marginal eigenvalue (i.e. its explanatory fit to the termite abundance and genera data as the only variable in the analysis). Subsequently, the soil (physical and chemicals) property variables were entered one at a time in order of the magnitude of their conditional eigenvalues (i.e. additional fit after adding previous variables), until none of the remaining variables significantly explained additional variation in the abundance of termites (Ter Braak and Smilauer, 1998). The lowest taxonomic level which was confined at the generic level were also evaluated through the linear ordination technique Redundancy Analysis (RDA). Data on termites' foraging activities were on the other hand assessed in every quadrant through (i) the length of tunneled soil surfaces and substrate (cm per 10,000 cm2) and (ii) through the number of pocked holes/ galleries at different top- and sub-soil (poked holes per 1,000 cm3) and the correlation between termite castes and genera and between foraging activities were tested using the r-corr function from the Hmisc package (Harrell, 2016).

3.3.4.3 Data analysis for injury patterns and extent of damage

Studies on injury types, patterns, and the extent to a large extent relied heavily on field observations that were summarized in field notebooks. Lodging damage involved as well counting lodged plants weekly i.e. as from 1st to the 20th weeks after emergence (WAE) and scored in percentage (%), after checking for outliers using the detection and seperation function from the brglm2 package (Kosmidis, 2019). When that was found to be true then the brglm function was used from the brglm package to conduct a bias-reduced generalized linear model (Kosmidis, 2019). A binomial distribution using a farming system, sampling date, and the interactions of these factors yielded, an i) analysis of deviance (Wald chi-square test) to check the significance of each factor using the Anova function from the car package (Fox and Weisberg, 2011), and ii) a posthoc Tukey test for pairwise comparison of farming systems using the emmeans function from the emmeans package (Lenth, 2019). iii) Additionally, analysis of deviance and posthoc tests were performed as described for lodging, if necessary. Assumptions for each model (heteroscedasticity and distribution) were tested graphically with a significant level for all statistical tests set at $p<0.05$.

The data collection for tunnel damage significantly relied on summary reports from the notebook then later expressed into percentage per plot (i.e. affected plants out of 12 from the quadrant) (Figure 3.3). The data were then tested with a generalized linear mixed-effect model with a binomial distribution against the farming system, season, and site as fixed factors and block as a random factor used and finally subjected to statistical analysis using R-Statistical software (R Core Team, 2019). The function lmer from the package lme4 (Bates et al, 2015) was then used to set up the model. The exact identity termite species associated with the damage symptoms of the maize crop cultivars were then determined from the collections through detailed morphological examination then identified to genus and even to species levels at the National Museum of Kenya and molecular studies.

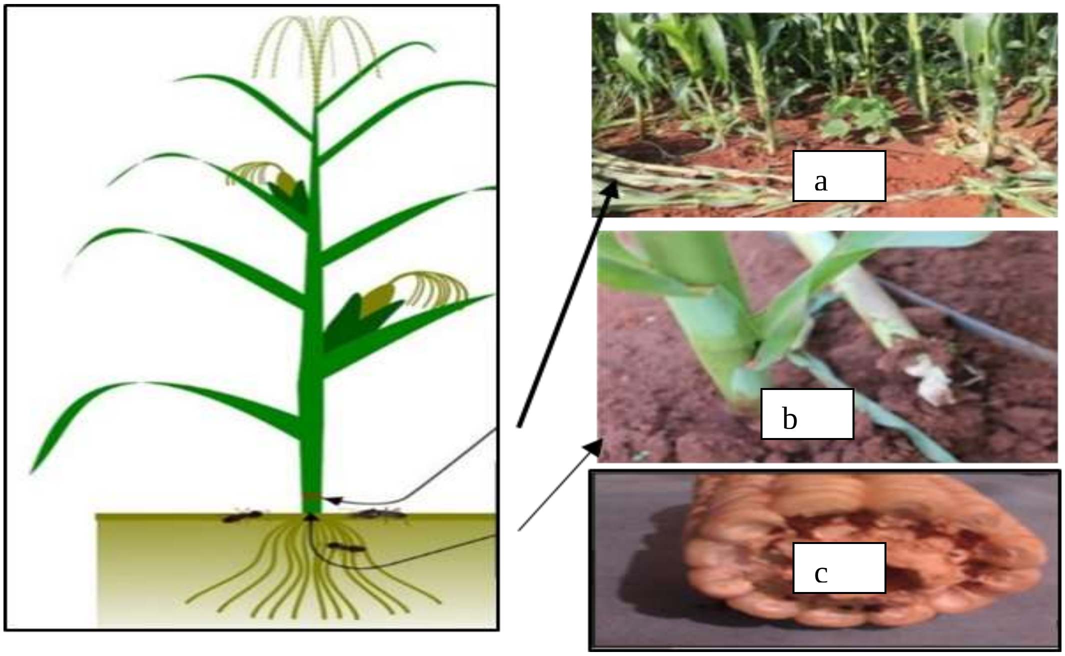


Plate 3.3: A lodging (a) and tunneling (b, c) symptoms done by termites on maize

3.5 Meteorological data

Meteorological data were collected at the two sites (Chuka and Thika); with data recorded on a daily basis being rainfall, temperature (minimum and maximum), and relative humidity (RH.) (minimum and maximum). The data on this are summarized under Appendix VII.

Plate 3.4: A bean crop field dominated trial 2nd season 2014

CHAPTER FOUR

RESULTS

4.1 Overview

This chapter summarizes effect of the long-term farming systems (namely Org-High, Conv-High, Conv-Low, and Org-Low) on termite abundance, and genera diversity at both the soil substrates and from within soil profiles. The effect of the farming system farm inputs changing soil physicochemical property after 7 years of continuous cropping are also reported. The emphasis here were on physical and chemical soil property and in relation to termite population over the period, the results accrued were obtained from field data subjected to rigorous statistical analysis. Effects of the farming systems on termite populations and termite pest activities were further determined on the injury types, patterns, and extents of damage caused on maize cultivars. The termite identity associated with maize cultivar damage were finally identified and results summarized.

4.2 Effects of farm inputs

Effect of farm inputs were summarized and the results are under Tables 4.1, 4.2, 4.3, 4.4, and Appendix II, The results were firstly recapped under the substrates separately from within soil profiles in all cases showing significant ($p < 0.001$) effects on termite indices led by abundance and diversity.

4.2.1 Termite population abundance and diversities as affected by farm inputs

4.2.1.1 Farming system effect above soil surface and at substrate levels

Effect of farm inputs on termite abundance at the soil substrate (i.e. above topsoil), an area measuring 100 cm x 100 cm and repeated 4 times per plot were found to vary i.e. dependent on farm input types and amount supplied to the systems. For example, consistently higher termite abundance occurred under Org-High when compared to all other farming systems. Under the preferred system averaging 38.2 ± 7.5 total termites which were significantly ($p<0.001$) higher than all others (i.e. Conv-High, Org-Low, and Conv-Low) which registered just between 2.2 and 3.2 individual termites per plot. The trial site was the factor found to influence termite abundance significantly ($p<0.001$) higher termite abundance by a 2.5 times factor more in favor at Chuka than Thika (Appendix 2). The seasonal cropping influence was yet another factor that significantly ($p < 0.001$) affected on termite abundance in favor of 2nd season than under 1st and 3rd seasons by a 1.5 times more termites recorded in abundance.

4.2.1.2 Farming system effect within soil profile

When it came to within soil profile the farming systems effect on termite average abundance were significantly ($p < 0.001$) affected in favor of Org-High farming system. For example from a 2,000 cm^3 soil volume drawn from the top- soil higher termite abundance was recorded compared to from the sub- soils. The effect of soil profile still as a factor again significantly ($p < 0.001$) higher termite average abundance were recorded i.e. numbering 26.3±3.5 as compared to just about 3.6 to 4.0 termites from the sub-soil profiles. All were from the same soil volume a result that can be expressed to be 4 to 7 times lower under the Org-High farming system (Appendix 2).

Table 4.1: Total average number of termites and termite caste in the substrate, top- and sub- as affected by organic and conventional farming system inputs in the farming systems comparisons trials at Chuka and Thika, the Central Highlands of Kenya

		Abundance		
	Total	**Worker**	**Soldier**	**Immature**
Source of variation for substrate				
Farming system	***	***	***	***
Season	***	***	***	***
Site	**	**	***	**
Farming system x season	***	***	***	***
Farming system x site	***	***	***	***
Farming system x site x season	***	***	***	***
Source of variation for soil				
Farming system	***	***	***	***
Depth	***	***	***	***
Season	***	***	***	***
Site	***	***	**	***
Farming system x depth	***	***	***	***
Farming system x season	***	***	*	***
Farming system x site	***	***	***	***
Farming system x depth x season	**	**	Ns	**
Farming system x site x depth	*	*	***	Ns
Farming system x site x season	***	***	***	***
Farming system x depth x season x site	Ns	ns	ns	Ns

Legend: Significant differences between farming system, site, season, depth or their interactions are indicated by * ($p < 0.05$), ** ($p <0.01$), *** ($p < 0.001$ or ns not significant)

4.2.1.3 Termite abundance as affected by trial sites and cropping seasons along soil profiles

Over the trial periods, termite average abundance within soil profile were again found to be affected by trial sites i.e. Chuka recording an averagely of 62.7±1.3 termites than at Thika. This was more the case under the Org-High farming system having a significantly ($p < 0.001$) higher termite value in the 2nd compared to the 1st and 3rd seasons recording averaging just about 30.6±1.2 and 32.3±1.0) termites respectively at Chuka site. The same significant differences between seasons were also found with Conv-High at Chuka (11.5±1.3 compared to 5.0±1.2 and 3.7±1.0). At Thika, a similar trend for the cropping seasons was discovered with Org-High showing significantly (p<0.001) higher values in the 2nd (19.5±1.4) and 3rd (19.8±1.0) season compared to 1st season. The later recorded just 6.1±1.2 average termite numbers).

The cropping season also showed effect with the 2nd season and particularly so at Chuka site where the termite population registered (44.0 ± 3.8) whereas at Thika, even higher numbers (88.8±4.0) of the termites were recorded. Similarly in the 3rd season and at Thika (termite numbering 47.6±3.0) were also registered in higher numbers under the Org-High system being significantly (p<0.001) differed than at Chuka. At the later site for example termite values in the 2nd season (were 44.0±3.8) which again significantly (p<0.001) differed being higher than in the 1st season (15.5±3.3) and 3rd season where just 14.9±3.0 termite in numbers were registered. The two seasons (1st and 3rd) were however insignificantly different between themselves. On the other hand, at Thika, the value for the 2nd season (recorded average 88.8±4.0 number of termites in abundance) a value that significantly (p < 0.001) differed being higher than the value in the 3rd season numbering just (47.6±3.0) termites. These were significantly (p < 0.001) higher than the value from the 1st season (16.4±3.4). In addition, values found for Org-High at both sites were significantly (p<0.001) different from each other in the 2nd and 3rd season, showing higher values at Thika (88.8±4.0 and 47.6±3.0) compared to at Chuka (where 44.0±3.8 and 14.9±3.0 numbers were recorded).

Average termite castles (workers and immatures) abundance within soil profile similarly experienced the same trends just like for total number whose averages numbers are summarized in Table 4.1 and Appendix 2. Such results were further confirmed by the significant positive (p < 0.001) correlation of abundance of termite workers (r = 0.99) and immature (r = 1.00) within soil profiles (Table 4.2). The average abundance of termite soldiers (997 individuals found) still showed a smaller, but significant (p < 0.001) positive correlation (r = 0.76) with the abundance of total number of termites in soil under Org-High. No other system showed significant difference between the seasons.

The interaction between the farming system * site* season * soil profile on total average termite abundance further showed similar significant ($p < 0.001$) higher termite abundance in favor of Org-High (Table 4.1). A second significant ($p < 0.01$) interaction of farming system * depth * season for an average abundance of the total number of termites in the topsoil and subsoil were also found from the statistical analysis (Table 4.1). The last significant interaction ($p < 0.05$) was also found for the farming system * depth * site (Table 4.1) but still showed that the values for Org-High were significantly higher at both sites and depths compared to all other systems (overall seasons). Furthermore, significant differences between topsoil and subsoil within Org-High were present with values for the topsoil at Chuka and Thika (46.4±1.0 and 23.7±1.0) showing significantly ($p<0.001$) higher termite abundance as compared to sub-soils whose values were (numbering 37.3±1.0 and 6.6±1.0) termites at both the sites.

4.2.2 Termites bio-diversity: genera abundance and richness

4.2.2.1 Termite genera abundance

Identified termite diversities over the study period were classified and found to belong to nine (9) termite genera. For example from the 2,669 termite soldiers encountered at Chuka and the 2,358 at Thika and identified morphologically the termites mainly belonging the Termitidae family were encountered. A further classification on them grouped them as members of three sub-families namely: (i) Macrotermitinae (of genera: *Allodontotermes, Ancistrotermes, Macrotermes, Microtermes, Odontotermes* and *Pseudocanthotermes*), (ii) Termitinae (of genera: *Amitermes* and *Cubitermes*) and (iii) Nasutitiermitinae (of genera: *Trinervitermes*) (Table 4.3). In terms of total abundance per genera, the *Macrotermes* (1,641) were most abundant, closely followed by *Microtermes* (1,505) with the other extreme lowest being members of the *Ancistrotermes* (36) and *Allodontotermes* (37). Furthermore, the genera *Allodontotermes* and *Ancistrotermes* occurred exclusively at Chuka, as Odontotermes were found exclusively at Thika see Table 4.3.

Several significant factors and interactions influencing termites relative abundances were further revealed from statistical analysis i.e. termite genera *Microtermes* showed significant ($p < 0.001$) interactions between farming system * soil depth * site. Again highest average relative abundance for *Microtermes* (farming system * depth) were also found under Org-Low but only at topsoil (52.16 %), which was significantly higher ($p < 0.001$) than average relative abundance in the same farming system in the substrate (24.03 %) and subsoil (22.36 %). Also, the relative abundance of *Microtermes* was lower for all farming systems in the substrate (i.e. being just between 13.92 and 24.03 %).

Regarding the farming system * site interaction, it could be revealed, that Org-High (24.42 %) showed a significantly smaller ($p < 0.001$) relative abundance compared to the other farming systems at Chuka (41.75 – 44.45 %), while at Thika Org-Low (35.05 %) and Org-High (30.72 %) performed significantly higher ($p < 0.001$) than Conv-Low (7.56 %) and Conv-High (12.68 %). Results for the termite genera *Macrotermes* Table 4.3 also revealed several significant interactions between farming system * soil depth * trial sites * cropping seasons. For example, significant farming system * trial site * soil depth interaction ($p < 0.001$) showed that there were no significant differences between and within farming systems during all seasons and depths at Chuka. In contrast, at Thika, the study revealed the relative abundance in the substrate in Conv-Low (49.20 %), similarly to the topsoil (29.07 %), but insignificantly so at subsoil (0 %). Furthermore, the relative abundance for Org-Low was high in the substrate (46.76 %) and the subsoil (49.99 %) and significantly higher compared to the topsoil (4.62 %). Significant differences within Org-High and Conv-High at Thika could not be found.

The significant ($p < 0.01$) farming system * trial site * cropping season interaction also showed some differences within the Conv-High farming system. Compared to the other farming systems, which did not show any significant differences, the relative abundance of Conv-High at Chuka in the 1st season (44.29 %) was significantly higher compared to the values found at Thika in the 2nd (7.44 %) and 3rd season (8.91 %) were realized. The significant farming system * soil depth * cropping season interaction ($p < 0.05$) showed that the farming system Conv-Low performed highest in the topsoil in the 1st season (45.80 %) which was significantly different to Org-Low in the same season in the same depth (7.76 %) and Conv-Low in the subsoil in the 2nd season (4.97 %). These genera were found in variable abundances under soil substrates and within soil profiles.

Other significant differences for this interaction could not be discovered in Table 4.3. The average relative abundance of the genera *Cubitermes* (farming system * season) was highest in low input systems, in the 2nd season (Conv-Low: 27.11 %; Org-Low: 27.44 %). The other values for these farming systems were lower in the 1st season (15.64 and 12.28 %) and 3rd season (9.53 and 10.56 %) but never differed significantly. The values for high input system Conv-High and Org-High never exceeded 16 % in all the seasons and were even significantly different in the 3rd season for Conv-High (6.90 %) and in the 1st season for Org-High (9.13 %) compared to the values reported above for Conv-Low in the 2nd season. The significant farming system * site interaction ($p < 0.001$) showed differences between the average relative abundance of the termite genera *Cubitermes* in the conventional systems. The values for Conv-Low and Conv-High were significantly higher at Thika (27.07 and 20.26 %) compare to Chuka (10.47 and 4.75 %). The same effect was not present for the organic systems.

The results for the average relative abundance of the termite genera *Odontotermes* (farming system * site) showed the highest value for Conv-High at Thika (40.03 %), which was significantly different from the other farming systems at Chuka which never recorded its presence. The farming system Org-High showed the lowest relative abundance at Thika (8.71 %) which was even significantly different from the values found for both conventional systems (25.47 and 40.02 %). Furthermore, the significant farming system * depth interaction ($p < 0.05$) showed that the Conv-High farming system showed higher values in the substrate (45.89 %), which was significantly higher compared to the topsoil (20.20 %) and subsoil (3.12 %). Average relative abundance of the termite genera *Pseudocanthotermes* showed a significant farming system effect: The relative abundance in Org-High (11.24 %) was significantly higher ($p < 0.05$) compared to Org-Low (5.83 %). For the average relative abundance of the termite genera *Trinervitermes* a significant farming system * season effect ($p < 0.05$) could be discovered: Highest relative abundance was found for Conv-Low in the 3rd season (8.74 %) which was significantly higher than the value for Conv-Low in the 1st season (1.19 %). The other farming system did not show a significant difference between the seasons' Table 4.3. A significant interaction for *Trinervitermes* involving farming system and depth could not be revealed. Nonetheless, the analysis revealed a significant depth effect ($p < 0.01$) for the general. The relative abundance for *Trinervitermes* was significantly higher in the subsoil (6.07 %) compared to the topsoil (3.16 %) and the substrate (0.36 %). The results for the average relative abundance of the termite genera *Ancistrotermes* and *Allodontotermes* only showed a significant site effect ($p < 0.05$) as both genera were only present at Chuka and not at Thika. Significant effects involving farming systems could not be revealed.

Table 4.2: Source of variation for average relative abundance of termite genera in organic and conventional farming systems comparisons trials at Chuka and Thika, Central Highlands of Kenya

	Microtermes	**Macrotermes**	**Cubitermes**	**Odontotermes**	**Pseudacanthotermes**	**Amitermes**	**Trinervitermes**	**Ancistrotermes**	**Allodontotermes**
Source of variation									
Farming system	Ns	***	Ns	***	*	Ns	Ns	Ns	Ns
Depth	**	*	Ns	**	Ns	***	**	Ns	Ns
Season	Ns	Ns	***	Ns	Ns	Ns	Ns	*	*
Site	***	Ns	*	***	Ns	Ns	Ns	Ns	Ns
Farming system x depth	***	***	Ns	*	Ns	**	Ns	Ns	Ns
Farming system x season	Ns	Ns	*	Ns	Ns	Ns	*	Ns	Ns
Farming system x site	***	***	***	***	Ns	***	Ns	Ns	Ns
Farming system x depth x season	Ns	*	Ns	Ns	Ns	Ns	Ns	Ns	Ns
Farming system x site x depth	Ns	***	Ns	Ns	Ns	***	Ns	Ns	Ns
Farming system x site x season	Ns	**	Ns	Ns	Ns	Ns	Ns	Ns	Ns
Farming system x depth x season x site	Ns	Ns	Ns	Ns	Ns	Ns	Ns	Ns	Ns

Legend: Conv-Low, conventional low input farming system; Org-Low, organic low input farming system; Conv-High, conventional high input farming system; Org-High, Organic high input farming system; ns, not significant

NB: Significant differences between farming system, site, season, depth or their interactions are indicated by * ($p < 0.05$), ** ($p < 0.01$) *** ($p < 0.001$) or; ns non-significant. Specifications (fixed and random factors) of the linear model can be found in the chapter “Methods”

Table 4.3: Correlation of termite abundance between termite soldier genera in the long-term farming systems comparisons trial sites at Chuka and Thika in the Central highlands of Kenya

	Allodonotermes	*Amitermes*	*Ancistrotermes*	*Cubitermes*	*Macrotermes*	*Microtermes*	*Odontotermes*	*Pseudacanthotermes*	*Trinervitermes*
Allodontotermes	1.00	0.26***	0.91***	0.32***	0.26***	0.25***	-0.10	0.18***	0.10*
Amitermes		1.00	0.27***	0.22***	0.25***	0.22***	-0.12*	0.23***	0.39***
Ancistrotermes			1.00	0.32***	0.29***	0.27***	-0.10	0.19***	0.12*
Cubitermes				1.00	0.72***	0.51***	0.23***	0.60***	0.39***
Macrotermes					1.00	0.60***	0.42***	0.70***	0.31***
Microtermes						1.00	0.11*	0.45***	0.25***
Odontotermes							1.00	0.35***	-0.09
Pseudacanthotermes								1.00	0.27***
Trinervitermes									1.00

NB: Significant differences between farming system, site, season, depth or their interactions are indicated by * ($p < 0.05$), ** ($p < 0.01$) or *** ($p < 0.001$); Specifications (fixed and random factors) of the linear model can be found in the chapter

4.2.2.2 Termite genera richness

Among the termite soldier genera there were several correlations: Allodontotermes and Ancistrotermes (r = 0.91), Macrotermes and Cubitermes (r = 0.72), Pseudocanthotermes and Macrotermes (r = 0.70), Pseudocanthotermes and Cubitermes (r = 0.60), Microtermes and Macrotermes (r = 0.60), and Microtermes and Cubitermes (r = 0.50) all showing a significant positive ($p < 0.001$) correlation (Table 4.4).

Table 4.4: Average values per treatment and source of variation for species richness (S), the incidence-based coverage estimator of species richness (ICE), the estimator of species richness Chao2, and the Shannon index (Sh) in the substrates, top- and sub- soils in organic and conventional farming systems in the farming systems comparisons trials at Chuka and Thika, Central Highlands of Kenya

	S	Chao2	S_h
Source of variation at substrates			
Farming system	***	***	***
Depth	***	*	***
Season	**	Ns	*
Site	**	**	*
Farming system x depth	Ns	*	**
Farming system x season	*	*	ns
Farming system x site	Ns	Ns	ns
Farming system x depth x season	Ns	Ns	ns
Farming system x site x depth	Ns	Ns	*
Farming system x site x season	Ns	Ns	ns
Farming system x depth x season x site	Ns	Ns	ns
Source of variation from within soilprofiles			
Farming system	***	***	***
Depth	***	*	***
Season	**	ns	*
Site	**	**	*
Farming system x depth	Ns	*	**
Farming system x season	*	*	ns
Farming system x site	Ns	ns	ns
Farming system x depth x season	Ns	ns	ns
Farming system x site x depth	Ns	ns	*
Farming system x site x season	Ns	ns	ns
Farming system x depth x season x site	Ns	ns	ns

ns, not significant NB: Significant differences between farming system, site, season, depth or their interactions are indicated by * ($p < 0.05$), ** ($p < 0.01$) or *** ($p < 0.001$); Specifications (fixed and random factors) of the linear model can be found in the chapter “Methods”

4.3 Farming systems effect on soil physiochemical properties and on termite incidence abundance

Under this section effect of farming system resulting in changes of soil physiochemical properties and how that influenced termite abundance were summarized. Tables 4.5, 4.6, 4.7, and 4.8, also Figures 4.1, 4.2, 4.3 and lastly under Appendixes 2 and 3) list the results.

4.3.1 Soil physical and chemical properties

Among the sandoil physical properties significantly ($p < 0.05$) influenced mainly under Org High farming system were the soil fraction contents (recording a 0.273%) change especially at Chuka. Such a change were never realized under all other systems (e.g. Org-Low, Conv-High, and Conv-Low). For them they only registered 0.196, 0.225, and 0,232% respectively (Appendix IV 4 and Table 4.5). Moisture retentions and wilting points too were yet the other soil physical properties found to be significantly ($p>0.01$) affected by the farming systems them recording 25.2% at Thika under Org-High and 23.03% for Conv-Low at Chuka.

The trial site as a factor on physical soil properties were similarly and in a significant ($p=0.02$) way affected at Chuka by 0.244% than at Thika (by just 0.145%) affecting soil fractions. Soil profile effects were also another factor found to affect soil bulkiness which were recorded within subsoil and at Thika (of a values 0.99%). Such a value were averagely higher than at Chuka (0.95%). The soil hydraulic conductivity at top soils again was significantly $p<0.05$ affected at Thika recording 0.019% as compared to at Chuka (where the recorded value was 0.022%) (Table 4.5).

On soil chemical properties significant ($p=0.001$) farming system effects occurred on the majority of the macronutrient elements contents such as Ca, Mg, C, and N. This was more so under Org-High than from all other farming systems. The exchangeable cation contents (e.g. for CEC, EC, and pH); and some micronutrients such as B and Cu too were similarly affected in a similar manner under the Org-High system (Appendix III and Table 4.5). Trial sites effects too as a factor also were significantly ($p < 0.05$) realized on some macronutrient contents led by Ca, N, and P in favor of Chuka while K and Mg occurred in higher contents at Thika. On seasonal effect again as a factor the C and P(O) contents were significantly ($p < 0.05$) affected in the 2nd than the other two seasons (i.e. 1st and 3rd Table 4.5).

4.3.2 Termite abundance against farming systems and as affected by soil physiochemical changes

4.3.2.1 Within soil profile

Among the soil physical properties, soil fraction contents were significantly ($p = 0.001$) influenced mainly under Org High farming system more at Chuka (recording 0.273%). That was the opposite of all other systems (Org-Low, Conv-High, and Conv-Low) which registered just 0.196, 0.225, and 0,232% respectively (see Appendix 4 and Table 4.5). Moisture retentions and wilting points were the other soil physical properties found to be significantly ($p>0.01$) affected by the farming systems them recording 25.2% at Thika under Org-High and 23.03% for Conv-Low at Chuka.

The trial site as a factor on physical soil properties was similarly and significantly ($p=0.02$) affected at Chuka by 0.244% than at Thika (by 0.145%) affecting soil fractions. Soil profile effects were also a factor affecting soil bulkiness recording within subsoil and at Thika (values of 0.99%) which were averagely higher than at Chuka (0.95%). The soil hydraulic conductivity at top soils again was significantly $p=0.01$ affected at Thika recording 0.019% as compared to at Chuka (where the recorded value was 0.022%) (Table 4.5).

On soil chemical properties significant ($p=0.001$) effects were recorded on the majority of the macronutrient elements contents such as Ca, Mg, C, and N; more so under Org-High than all other systems. The exchangeable cation contents (e.g. for CEC, EC, and pH); and some micronutrients such as B and Cu too were similarly affected in a similar manner under the Org-High system (Appendix 3 and Table 4.5). Trial sites effects too as a factor also were significantly ($p=0.001$) affected i.e. some macronutrient contents led by Ca, N, and P in favor of Chuka while K and Mg occurred in higher contents at Thika. On seasonal effect as a factor C and P(O) were noted as significantly affected in the 2nd season than the other two seasons (i.e. 1st and 3rd Table 4.5).

Table 4.5: Soil physical and chemical properties as affected by farming systems trial sites, cropping season and soil profiles

			Farming systems				Trial Sites		Seasons			Soil profile	
Type of property		**Soil properties**	Conv H	Org H	Conv L	Org L	Chuka	Thika	SI	SII	SIII	Top	Sub
Physic	Soil	Blk	Ns	Ns	Ns	Ns	ns	ns	Na	na	Na		***
		Soil fra	Ns	***	Ns	Ns	***	ns	Na	na	Na	na	na
	Water	Hyd Con	Ns	Ns	Ns	Ns	ns	ns	Na	na	Na		***
		Mo re	Ns	***	Ns	Ns	ns	***	Na	na	Na	na	na
		Wilt po	Ns	Ns	**	Ns	ns	ns	Na	na	Na	na	na
Chem	Macro	Ca	Ns	***	Ns	ns	*	Ns	*			Na	na
		K	*	Ns	Ns	ns	Ns	***	*			Na	na
		Mg	Ns	***	Ns	ns	Ns	*	*			Na	na
		C	Ns	Ns	Ns	ns	Ns	Ns		*		Na	na
		N	Ns	***	Ns	ns	**	Ns			*	Na	na
		P(O)	***	**	Ns	ns	**	Ns		*		Na	na
		CEC	Ns	***	Ns	ns	**	Ns		*		Na	na
	Each	EC	Ns	***	Ns	ns	Ns	**	*			Na	na
		pH	Ns	***	Ns	ns	Ns	Ns	*			Na	na
	Mic	Boron	Ns	**	Ns	ns	Ns	*	Na	na	na	Na	na
		Cu	Ns	Ns	Ns	ns	*	Ns	Na	na	na	Na	na
		Fe	***	Ns	Ns	ns	Ns	*	Na	na	na	Na	na
		S	Ns	Ns	Ns	ns	Ns	**	Na	na	na	Na	na
		Zn	Ns	*	Ns	ns	*	Ns	Na	na	na	Na	na
		Al	Ns	Ns	*	ns	Ns	*	Na	na	na	Na	na

ns, not significant, na, not applicable. NB: Significant differences between farming system, site, season, depth or their interactions are indicated by * ($p < 0.05$), ** ($p < 0.01$) or *** ($p < 0.001$); Specifications (fixed and random factors) of the linear model can be found in the chapter

Keys: Mac - Macronutrients; Exc - Exchangeable cations; Mic - Micronutrients Blk - Bulk density; Sol fra - Soilfraction/ Wet sieve; Hyd Con - Hydraulic Conductivity; Mo re - Moisture retention (% w/w basis); Wil pt - Wilting points

4.3.2.3 Termites population and soil physiochemical properties

Some macronutrients e.g. Ca, K, and N was affected in values being directly and in a significant ($p>0.05$) manner correlated with higher termite populations. Similarly higher values of CEC from among the exchangeable cations and the micronutrients (including Cu, S, and Al) were also directly correlated with higher termite abundance. A further assessment of the same involving the principal component analysis (PCA) and redundancy analysis (RDA) tools similarly established higher termite numbers explained by five key chemical elements explaining the high termite number. Most such chemicals elements accounted for up to 81.3% of the variances of termite populations with the following major element: pH - 38.1%, P (Olsen) - 24.5%, K - 7.5%, Ca - 6.2% and Mg - 4.9% accounted by them. This showed the remaining physical and chemical factors as having accounted for the remaining 19% termite abundances (Figure 4.3 and Table 4.9). Termite diversities to genera level were further found to be affected by the chemical factors the most important elements being Ca, C, and N contents. These elements positively related with members of the termite genera e.g. *Allodontotermes*, *Ancistrotermes*, *Trinervitermes*, and *Amitermes* with the exception being *Odontotermes* that exclusively occurred at the Thika site only.

Table 4.6: Termite incidence abundance within soil profile (top- compared to sub-soils)

	Total incidence abundance			
	Total	***Worker***	***Soldier***	***Immature***
Source of variation for soil				
Farming system	***	***	***	***
Depth	***	***	***	***
Season	***	***	***	***
Site	***	***	***	***
Farming system x depth	***	***	***	***
Farming system x season	***	***	***	***
Farming system x site	***	***	***	***
Farming system x depth x season	*Ns*	*Ns*	*Ns*	*ns*
Farming system x site x depth	***	***	***	***
Farming system x site x season	**	***	***	*ns*
Farming system x depth x season x site	*ns*	*	*Ns*	*``

Legend: total number of termites and termite caste in top- and subsoil and in organic and conventional farming systems in the farming systems comparisons trials at Chuka and Thika, the Central Highlands of Kenya ns, not significant;

NB: Significant differences between farming system, site, season, depth or their interactions are indicated by * ($p < 0.05$), ** ($p <0.01$) or *** ($p < 0.001$)

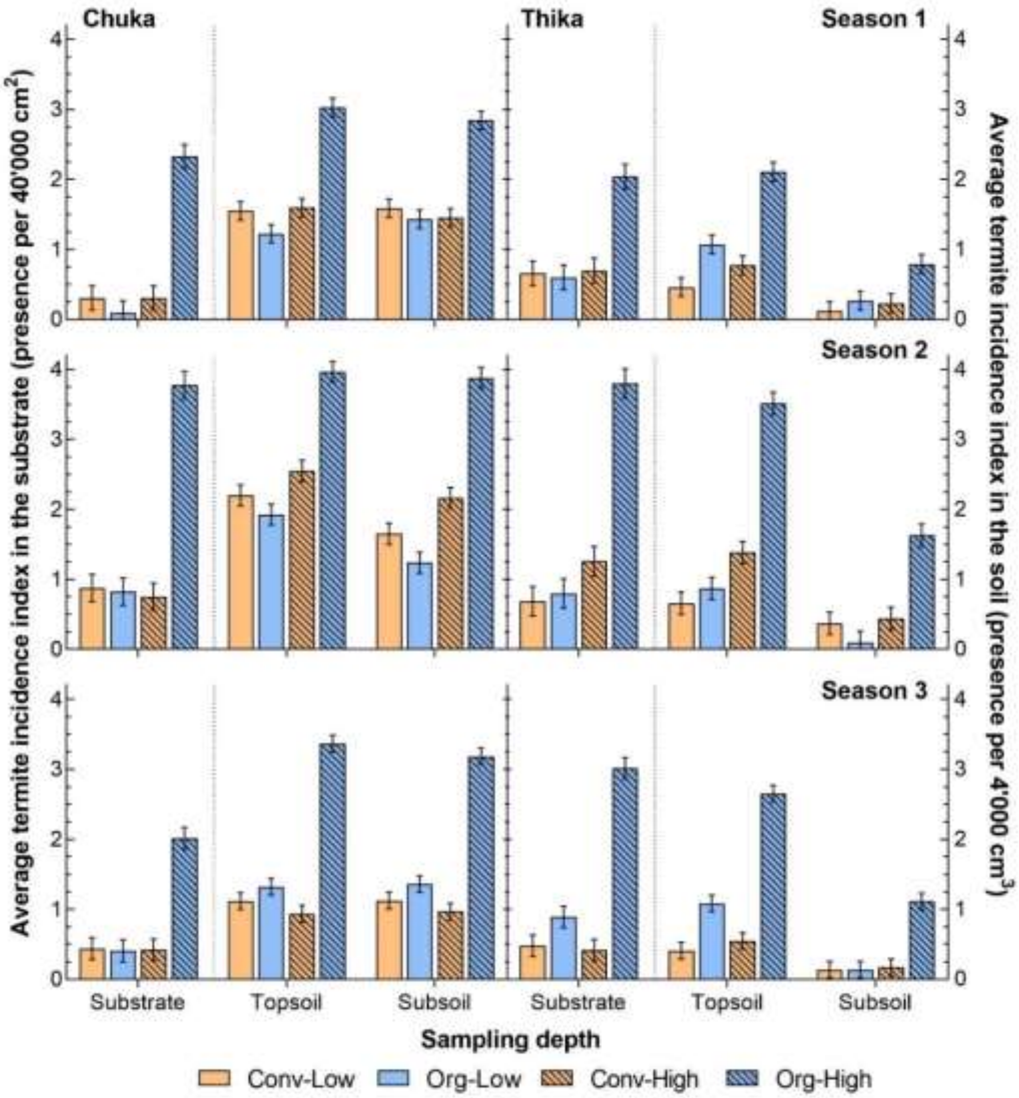


Figure 4.1: Average termite incidence index (0: not present at all, 4: always present) for total number of termite in organic and conventional farming systems at substrate, top and subsoil during 1st season 2014 (season 1), 2nd season 2014 (season 2) and 1st season 2015 (season 3) in the farming systems comparisons trials at Chuka and Thika, Central Highlands of Kenya.

Table 4.7: The key soil factors influencing termite abundance (from whole soil)

Soil element properties	% of Variance
pH	43.18
P(Olsen)	22.07
K	8.51
Ca	5.02
Mg	3.49
Na	3.1
EC	2.7
CEC	1.96
C	1.77
N	1.27

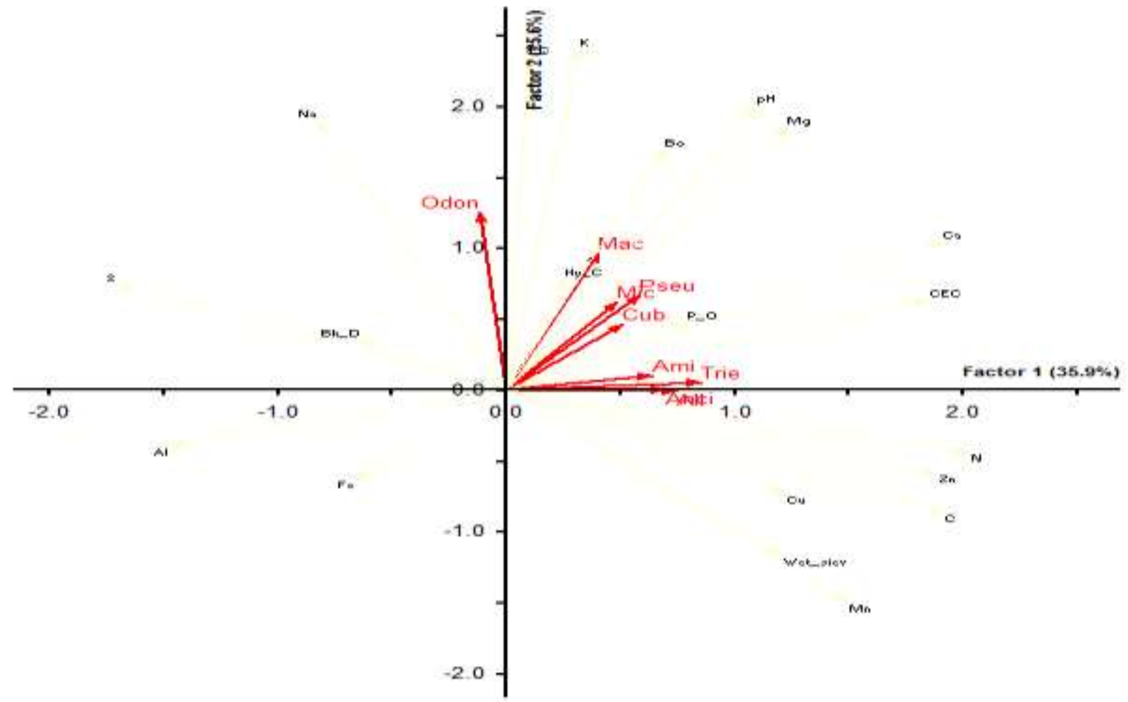


Figure 4.2: PCA analysis of Chemical properties, Physical properties Termite abundance and termite diversity abundance for Chuka and Thika sites. The first two axis explained 63.6% of the total variance- axis1 (38.1%) and axis2 (24.5%).Axis1

4 3.2.4 Termites population relationship to foraging activities

Termite foraging activities a measure of extent by which soils physical properties were affected by farming systems within soil profile and at the substrate also established significant termite tunneling activity (measured in cm) and on the number of pocked galleries Table 4.8 and Figure 4.4. The highest average tunneling (87.9±12.4 cm) and gallery recording 36.6±3.3 (pocked holes) were recorded under Org-High system; values which could be expressed to be higher by 30-40 and 8-14 times higher for the tunneling and galleries respectively when compared to all other systems. A three-way interaction statistical analysis farming system * trial site * cropping season showed a significantly higher ($p < 0.001$) tunneling activities in the substrate with highest value found in 2nd season at Thika under Org-High system (recording 282.3±4.7 cm per 10’000 cm^2) followed by the 3rd season at the same site and farming system (108.7±3.5) for Org-High which were significantly different from the values found in the other farming systems at the same sites and seasons. The only exception was found in the 1st season at Chuka, where all tunneling activities in the farming systems, including Org-High (14.8±3.9), were not significantly different from each other. Furthermore, all values found for Org-High at Thika were significantly higher than the values found for Org-High at Chuka.

Results for average gallery showed a significant farming system * soil depth * cropping season interaction ($p < 0.001$) Org-High system recording highest values compared to all other farming systems in each season and soil depth (over trial sites). Nonetheless, it showed several significant differences within Org-High average gallery activity being higher in the topsoil in the 1st (38.8±2.2 poked holed per 1’000 cm^3 soil), 2nd (70.2±2.5) and 3rd season (62.1±2.0) compared to the subsoil (14.9±2.2, 23.4±2.5 and 15.7±2.0). Furthermore, values in top-soils for Org-High were significantly higher in the 2nd (70.2±2.5) and 3rd season (62.1±2.0) compared to the 1st season (38.8±2.2). This could not be shown for the subsoil in Org-High or any other system. In addition, the result further revealed that within the farming system Org-High, values at Chuka in the 2nd season (62.6±2.4) were higher than in the 1st (35.2±2.2) and 3rd season (42.2±2.0). At Thika, the values for Org-High in the 2nd season (31.0±2.6) were only significantly higher than the 1st season (18.6±2.2), but similar to the 3rd season (35.6±2.6). In addition, it could be shown that average tunneling for Org-High were significantly higher at Chuka (35.2±2.2 and 62.6±2.4) compared to at Thika in the 1st (18.6±2.2) and 2nd season (31.0±2.6) Figure 4.3).

Table 4.8: Source of variation for average termite tunneling and gallery activity in organic and conventional farming systems in the farming systems comparisons trials at Chuka and Thika, Central Highlands of Kenya

	Tunnelling	**Gallery**
Source of variation		
Farming system	***	***
Depth	Na	***
Season	***	***
Site	***	**
Farming system x depth	Na	***
Farming system x season	***	***
Farming system x site	***	***
Farming system x depth x season	Na	***
Farming system x site x depth	Na	Ns
Farming system x site x season	***	**
Farming system x depth x season x site	Na	Ns

ns, not significant NB: Significant differences between farming system, site, season, depth or their interactions are indicated by * ($p < 0.05$), ** ($p < 0.01$) or *** ($p < 0.001$); - no sampling done

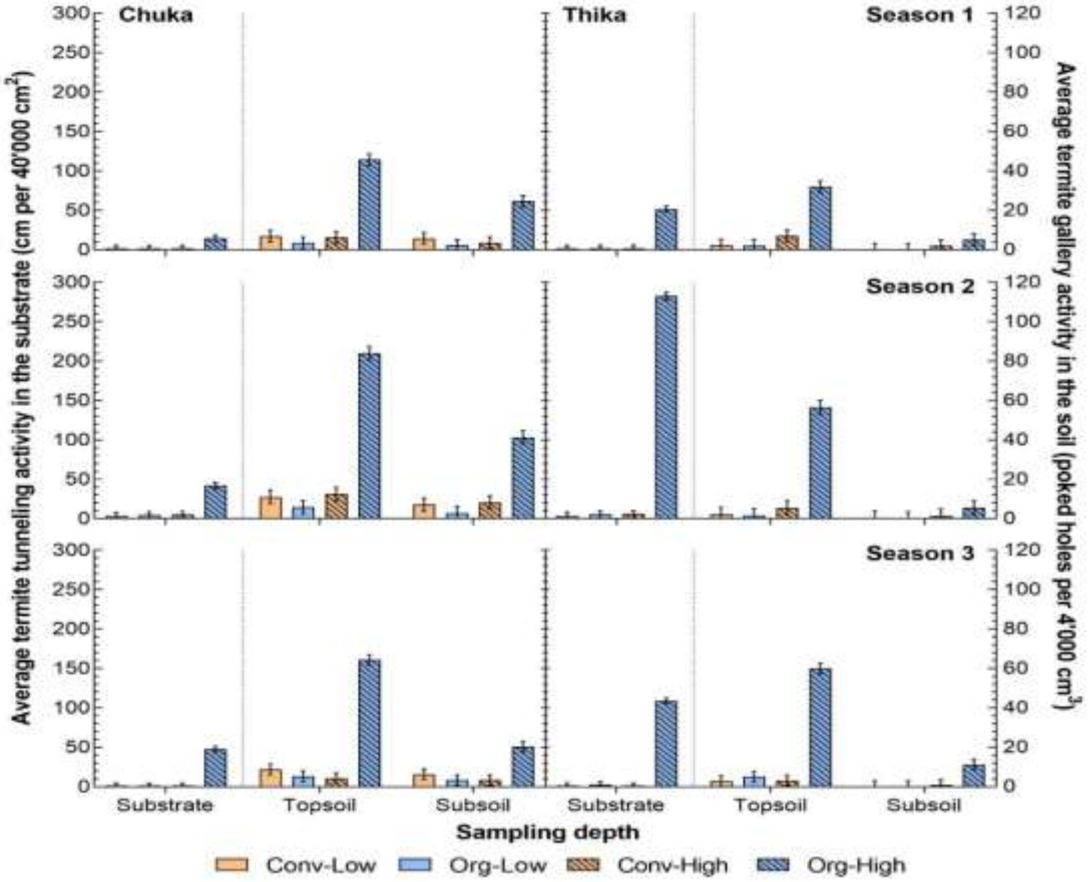


Figure 4.3: Average termite tunneling and gallery activity in organic and conventional farming systems at substrate, top and subsoil during 1st season 2014 (season 1), 2nd season 2014 (season 2) and 1st season 2015 (season 3) in the farming systems comparisons trials at Chuka and Thika, Central Highlands of Kenya.

Conv-Low = conventional low input farming system, Org-Low = organic low input farming system, Conv-High = conventional high input farming system, Org-High = organic high input farming system

4.4 Termite damage to maize crop

Results on termites' pest activities explaining the types, extent, patterns identifying termite species responsible were summarized from field data and general observation under Table 4.9, Figures 4.4 and 4.5, and Appendix VI.

4.4.1 Types, patterns, and extent of damage by termites

Termites' pest activities under the current studies established injuries by termites' feeding actions. These qualified termites as important pests causing damage to maize (*Zea mays* L.) crop. The injuries caused damage symptoms including wilting, lodge-off and fall-down, tunneling, and hollowing. "Earthling" was yet another symptom associated and severally confusable; a damage later dismissed as affected plant tissues later cleared off, the tissues later becoming blemish less over time. Out of these symptoms, however, it was lodging and tunneling to maize that were classified as the most important types of damage by termites necessitating attention and causing serious concerns the damage type later rated as the most important to the crop, initially appearing on the otherwise previously healthy looking plant that suddenly wilted and immediately fell to the ground.

Closer observation of such damaged maize severally revealed the presence of a cleanly cut base and lodged-off plant. Field observations revealed varied damage symptoms varied with farming system differences. For example, the dry maize cultivars seedlings under the Org-Low system firstly experience early lodging i.e. as from 2 WAE and peaked at 7 WAE. Other farming systems also showed similar lodging symptoms occurring and displayed similar symptoms but as as from maturing maize plant stage. Here the cut and lodged maize base displayed oozed water. Occasionally the cut maize seedlings were dragged by the termite colony to the underground gallery pathways but rarely to mature plants. To closely spaced and maturing maize the chopped maize remained in a "standing" position but in reality, being supported in the upward position by the neighboring plants. Such plant later dried and a fall-off to the ground the lodging damage compromising crop stand and required replanting (gapping). Lodging damage hence required an extra cost to growers (Figure 4.4 and Appendix VI).

To the dry maize cultivar also grown under the Conv-Low system similarl lodging pattern was experienced but in a lowly and gradual manner but from late vegetative to mature crop stage; recording inferior numbers (Table 4.9 and Figure 4.4). Such lodging damage to the dry maize (under Conv-Low system) further intensified from browning into crop drying stages i.e. just the cultivar attaining the recommended grain moisture content of 12.5% (Appendix VI). Such termite damage were hence of moderate economic importance unless early harvesting were conducted at the 18 WAE. Termites' pest activity were hence of moderate economic importance who might require labor to do premature harvesting and the provision of storage space for the produce.

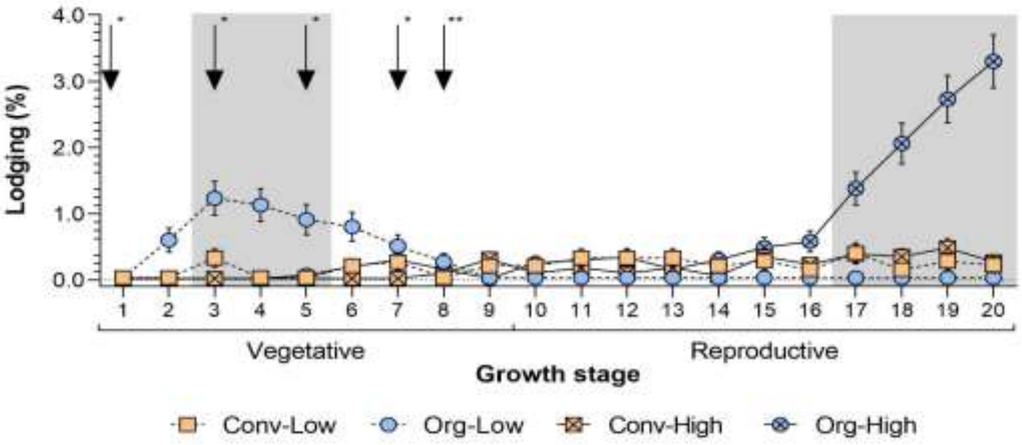
To the baby corn maize cultivar severer termite lodging was recorded to occur from 18 to 20 WAE (Figure 4.4). Termites hence are a relevant key pest to the cultivar causing variable damage attained but not during its peak harvest period. The peak harvest of the fresh cobs occurred between 3rd to 17th harvesting crop stages (see Appendix VI). From then subsequent high lodging damage which occurred after peak harvest by termites was classified as of low economic importance causing less than 5% of crop losses (Table4.9 and Figure 4.4).

Tunneling symptom was the other damage type associated with termites. Here the termites initially cause bark-ringing, and through feeding action cause root-trimming below the soil surface; termites enter through root hairs and prop roots. From here the termites extended their foraging and excavation activities inside maize stems, affected plants that way became hollowed, at times wilted following the disrupted nutrient and water. Such plants would wilt and dry-off. Closer examination of such plants revealed a hollowed and tunnel plant stems, containing a mixture of soil, feces, and dead termite cadavers inside maize stem. Such a crop would be pre-disposable, easily toppled-off by any slightest movements. Statistical analysis of the tunneling damage showed no significant differences with farming systems and hence classified as of minor economic importance i.e. below 5% (Table 4.9 and Figure 4.5).

Lastly “earthling damage” was yet the other symptom” severally viewed as a termite damage following termite shelter constructions using earth or mud on plant surfaces. It was of minor economic importance, only noted after periods of dry spell, with no particular pattern noted. Data collection for such a “damage type” were discontinued since the constructed runways and earthen tubes cleared cleared-off over the cropping seasons (2014 and 2015).

Table 4.9: Results of the statistical analysis for the fixed effects on lodging and tunneling damage (in % affected plants) in the long-term farming systems comparison trial sites at Chuka and Thika

		Lodging		**Tunneling**	
	Df	χ^2	$P > \chi^2$	χ^2	$P > \chi^2$
Farming systems	3	127.3752	< 0.001	2.9524	0.3990
Site	1	Na		0.2495	0.6175
Season	1	0.3607	0.5781	0.0380	0.8455
Sampling date	19	236.3193	< 0.001	Na	
Farming system x site	3	Na		0.4794	0.9234
Farming system x season	3	4.7070	0.1946	0.6050	0.8953
Farming systems x date	57	193.4888	< 0.001	Na	



Key: * Fertilizer application, ** Pesticide application to control Termites, gray areas show stages with significant difference between the farming systems

Figure 4.4: Lodging damage (in % affected plants per plot and growth stage) in the long-term experiment at Thika in the Central Highlands of Kenya

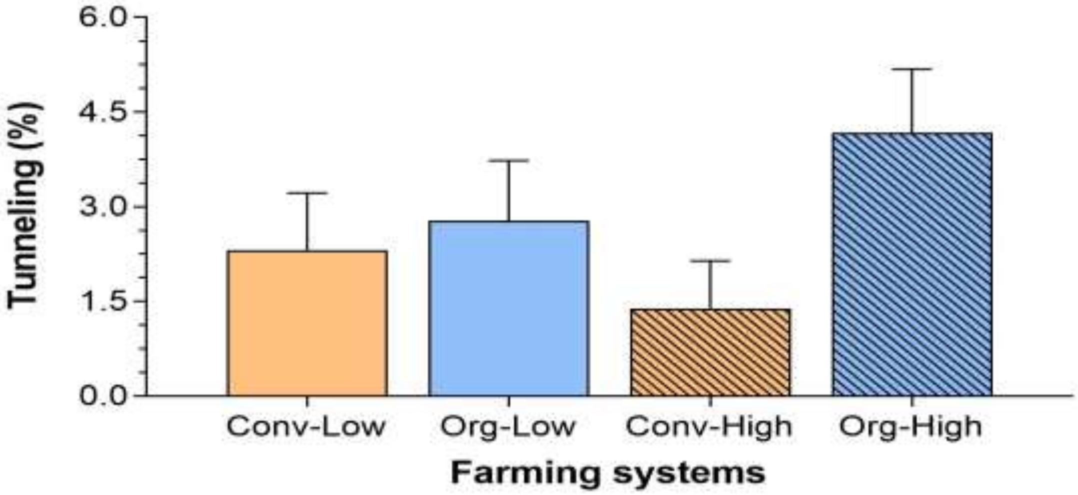


Figure 4.5: Tunneling damage pooled over both sites and seasons in the long-term experiment in the Central Highlands of Kenya

4.4.2 Pestorous termite species

Field sampling for the damaging termites' species was rather challenging. Sampling such termites proved hard the termites causing symptoms quickly sped-off into their galleries. This made their sampling and taxonomic identification rather difficult. All the same six times more termites in abundance were recorded under the Org-High farming system (i.e. averagely 22.57± 4.5) than other systems registering just Org-Low (3.71± 1.5), Conv-Low (3.57± 1.5), and Conv-High (3.35± 1.5). Statistical correlation between termite abundance showed no direct correspondence to termite damage i.e. the farming systems harboring higher termite abundance not necessarily having the most damaged maize crops. Instead, it was the reverse, i.e. the dry maize cultivars grown under the Org-How system and recorded higher seedling lodging damage. Similarly baby corn seedlings that were least affected by termites despite the Org-High system harboring abundant termites. Tunneling type of damage insignificantly occurred differently from among the farming system and even at site levels. Chuka site however recorded averagely twice the tunneled maize plants than at Thika. And whereas lodging termite damage was mostly associated with termite genera (species) *Odontotermes (O. somaliensis)*, *Macrotermes (M. herus* and *M. michaelseni*) and *Pseudacanthotermes (P. spiniger* and *P. militaris*) exclusively recorded at Thika the termite genera associated with tunneling damage at both sites associated with the termite genera: *Microtermes*, *Amitermes* and *Ancistrotermes*.

CHAPTER FIVE

DISCUSSIONS, CONCLUSIONS AND RECOMMENDATIONS

5.1 Overview

This chapter collectively examines the achieved results under the contrasting farming systems providing insights into possible reasons for the recorded higher termite abundance, genera biodiversity, and the levels of foraging activities. In particular termite indices against farming systems, farm inputs levels, differences in study sites, the cropping seasons and soil profiles are deliberated. Also changes in soil physicochemical properties and their pest status on maize crop cultivars against termite indices are highlighted; integrating obtained results and postulating the relation between termite populations for sustainable crop productivity rather than strictly a crop pests. The possibilities accepting the high termite high population in farms for purposes modifying soil ecological modification forms part of the major discussions, under the study conclusions and recommendations.

5.2 Discussion

5.2.1 Effects of farm inputs on termite populations

5.2.1.1 Farming system

Comparison of the four farming systems under investigation revealed that Org-High significantly and in a consistent manner promoted termites' abundance and diversity. It was the differences in farm inputs (i.e. the higher organic-based) received under the system that caused the promoted termite abundances. These inputs included farmyard manure (FYM), soil compost, dry rice mulch, the planted leguminous cover crops, combined with supplemented moisture through drip irrigation. These inputs were believed to have promoted of termite abundance; a similar observation having been reported by Ahmad, (2021). In his study such inputs were enumerated to process and release attractive gases claimed to be preferred and most attractive to termites thus promoting their abundance. Such inputs also enhanced termites foraging activities and promoted their habitations as such input materials are often endowed with cellulose and lignin contents, hypothesized to be ideal feeds for the termites (Bignell *et al.*, 2011).

In the current study, the Org-High farming system was observed to offer a conducive environment that promoted termites' survival, habitation, and population growth as were similarly found by Barrios, (2007) and Ngosong *et al.,* (2015). The surprising higher termite population initially reported at the beginning and that necessitated the termite studies to be conducted under LTE could therefore be related to the higher organic-based inputs; an input component forming part of the Org-High farming system since the 2007. All other farming systems including Conv-High, Conv-Low, and Org-Low received none or very little organic-based nutrient inputs and others even treated with inorganic chemical fertilizers and pesticides. Such inputs could have instead suppressed the termite population in the field (Ayuke, 2010).

5.2.1.2 Trial sites

Variable termite abundance and diversity occurred and were believed to as influenced by trial sites. The Chuka registered twice higher abundance when compared with Thika. The differences with geographical and agro-climatic conditions were believed as could have been the cause. For example, Thika site, lying in the drier as opposed to Chuka lying in cooler areas could have been part of the reason the slightly warmer/ hotter climatic conditions of the former site affecting termites' survival. The hotter temperatures are often perceived to negatively affect termites' survival causing them to occasionally desiccate leading to mass death; an assertion previously found by Jouquet et al., (2006). Hence the current study therefore affirms lower termite population at Thika could be negatively associated with the lower moisture recorded at the site and that could have most likely affected termite survival. Opposed to that was the Chuka site; lying in a semi-humid climate and receiving higher annual precipitation. Such cooler climate could have favored better termite survival and habitation as was similarly observed from other studies by Jouquet *et al.,* (2006).

The other possible reason for termite population different at the sites were hypothesized to do with soil content and soil texture differences. From physical soil assessment under the current study Chuka site soil content tended towards clayish as opposed to Thika whose content largely remained sandy since the beginning of the LTE. This could be part of the reason a similar assertion having been reported (Jouquet *et al.,* 2004). The later found clayish soils to promote termite abundance, taxonomic richness, and soil properties. Nhamo, (2004), in his finding also reported clayish soil content to enhance termites' biological and chemical functions than from sandy soils. Hence whereas from the beginning of the current trials the general observation at Chuka showed low termite population such a situation later changed, the site found to harbor higher termites population and soil content difference is believed to play a role.

Also from fieldwork again lower termites in abundance were discovered within the substrates at Chuka than at Thika. Closer observation later revealed the disparity to be associated with the high presence of ants repeatedly sampled from within the substrates i.e. above soil surface carrying plant residues) at the former site. A detailed field observation later identified resident ants aggressively cannibalizing termites whose cadavers were severally found scattered along pathways. The possibility of the ants becoming major termite predators at Chuka site and thus lowering termite population presented itself. Subsequent morphological identification of the same grouped them under family and genus names: *Nomamyrmex* (Formicidae, Ecitoninae). Further search from elsewhere reveals them as predators and that prey, scatters and scare termites through vibration cues (Oberst *et al.,* 2017). By doing so these ants naturally control termites. A further field research hence is recommended for the possible successful predation and to establish their biological control under the organic farming system.

5.2.1.3 Soil profiles

Differences in the soil profile as yet another factor found to play a role influencing termite population under the farming comparisons. For example, the uniformly structured soils at Chuka as opposed to the ones with hardpans at Thika were believed to be the reason for the uneven termite population distribution and abundance within soil profiles. Thika site, with tougher structured physical hardpans, could have largely influenced the highest termite concentrations just at top-soil as opposed to at Chuka with a generally uniformly structured soil profile, termites getting to be uniformly scattered throughout soil profile. The skewed distribution along with soil profiles at Thika, therefore, were further hypothesized to follow the permitted uniform and stratified organic matter distribution which are the preferred termite feeds; a finding that agreed with those by Cornelius and Osbrink, (2010); and Zida, (2011) who found termite distribution follow soil structure and food distribution.

5.2.1.4 Cropping seasons

Results from the current studies further revealed peak termite abundance occurring over the 2nd as opposed to 1st and 3rd cropping seasons. The cropping seasons hence became a key factor influencing termite population and abundance. For example, the bean-based dominant cropping over 2nd season was hypothesized as the reason as opposed to maize-based cropping over the 1st and 3rd seasons. The bean-based cropping with a dense canopy providing favorable termite habitation, a better habitat environment than the maize-based; that displayed a more exposed crop structure thus allowing for a wider fluctuating daily temperature and direct rainfall. A similar findings from other studies found such environment to be as less ideal for termites' survival (Sun, 2014). Hence the bean-based cropping with closer canopies provided better environment for termite survival a finding that corroborates and confirms the study hypotheses that termites are not resilient to conventional farming systems, where frequent disturbances of soil such as farm clearance every season using farm implements are the common farming norm. It further agrees with other study by Olugbemi, (2013) who affirmed higher termite abundance and diversity recorded under organic farming that severally embraced soil composting, mulching, cover crops plus supplement moisture similar to the Org-High farming system as a technology from the current study. The farming system further promises to promote a natural mass rearing of termite in farms; a technology if can be promoted in the region hopes spread quality and sustainable agricultural productivity with added advantages such as increased soil porosity and better water percolations to tropical region farms.

5.2.2 Farming systems effect on soil physiochemical properties and on termite population

5.2.2.1 Affected soil physiochemical properties

After seven (7) years of continuous farming under the contrasting farming practices, significant physical soil changes occurred under the Org-High system. The changed of soil. Other vital soil physical properties such as bulk density and hydraulic conductivity also changed though in insignificantly. Their changes are predicted as will occur and are in the process to eventually happen (Arévalo-Gardini *et al.*, 2015). Generally the soil physical often takes a while but will finally occur under contrasting farming (Musyoka et al., (2018). In the current study the short sampling interval i.e. 2007 since the trial commenced to 2014 when the first sol sample for this purpose was conducted and blamed for "slow changes". The soil fraction tending towards clayish content are particularly are in progress and especially at the Chuka site with the higher organic-based inputs have been hypothesized and claimed to be the cause. Such farm inputs combined with crop rotations, drip irrigation, and the absence of farm machinery plus the reduced human/ animal trafficking have been known to positively improve soil physical soil characteristics, elevate water retentions, improved soil health and allow for plenty of biodiversities and trigger soil changes for better crop productivity as were reported by Karhu *et al.*, (2011).

5.2.2.2 Farming systems

The current study further recorded drastic and significant soil chemical property changes under Org-High systems, chemical elements. They included macronutrients, exchangeable cations, and some micronutrients, with the probable reasons being the enhanced elements included the received organic natured inputs. These inputs are mineralized would enhance chemical elements and alter soil fertility and termite abundance as was stated by Ryals and Silver, (2013); an observation concurring with revelations by the farming communities' from Sub-Saharan Africa who from experience, and, however without any scientific backing associated termite hills with soil fertility (Vandecasteele *et al.,* 2004). The obtained results from the current studies hence affirm higher termites' population and if could be adopted and promoted the soil chemical, organo-mineral complexes, and biogeochemical cycling of nutrients to the farming communities the tropical region, then they will improve farm productivity, reduce underfeeding and is a worthwhile technology to be embraces as was similarly found by (Loko *et al.,* (2017).

Termite genera diversities again were recorded in higher numbers with the once identified being members of the Macrotermitinae sub-family; a termite having desirable qualities as trophic feeding, efficient soil transforming, and active promoters of chemical elements in tropical farms (Bignell, 2011); with other advantage to tropical farms experiencing low productivity and that evoked termite research to be undertaken under the LTE. The discovered termite group here also been discovered to have endogenous enzymes in their gut system; a property qualified them as efficient weathering agents, enhancers of chemical elements for the improvement of soil and plant production Musyoka (2019). Such similar sentiments were also expressed by Mujinya *et al.,* (2012) and Kihara *et al.,* (2015) them relating these termite group abundance positively with the stability of other microorganism species. Such an outcome related to under the Org-High system in the current study. Ngosong *et al.,* 2015) in his study further reported similar findings in agricultural farms and agrees with the current study hypothesis that higher termite in abundance would result in higher physiochemical property changes for the benefit and improvement of soils and plant growth following the generation of crop nutrients from within tropical farms often dominated by resource-poor farmers and to avoid reliance on the otherwise expensive and inorganic inputs. These farming communities might in the process “graduate” from just growing for subsistence into growing high valued crops for income generation. The technology hence would be worthwhile and its extension to the region promises drastic improvement for soil chemical nutrients starting with pH > P(Olsen) > K > and Ca > Mg among others all in line with healthy soils for profitable agriculture.

5.2.3 Termite pest activities

5.2.3.1 Pest activities under farming systems

The study on reasons for the high termite abundance also tried to relate found termite’s population with the extent they damage maize crops cultivars namely dry maize vs baby corn. Damage to the crop were mainly found to be depended on a number of factors. Beginning with farming system where the farm input type and amount significantly affected both termite abundance and crop healthiness. For example to dry maize seedling grown under Org-High system and that recorded both higher termite abundance as well as healthy looking and vigorously growing seedlings. Under the same plots levels of retained organic natured inputs were at various stages of mineralization and depletions. The maize seedling under the systems however never experienced serious lodging damage past vegetative until it reached senescence crop stage (Appendix VI). At the same time the baby corn cultivar had acquired woody and ligneous structures; a stage often preferred by termites as feeds (La Fage and Nutting, 1978). The termites therefore caused significant lodging damage but to a crop at senescence stage. By then and from field observation, the higher organic natured inputs under the Org-High system started to become depleted, the bulk manures from the input having been eaten by the abundant termites. Again by then the crop were also advancing in age and a scenario that could have forced the huge termite populations to change their feeding preferences, i.e. going for the crop and thus causing substantial lodging damage. This however happened to the senescencing baby corn crop stage under (Org-High system) towards the end of the trial. By then the termites had no more organics inputs to feed and that changed their feeding preference thus damaging the crop under the systems. The maize cultivar hence experienced increasing lodging damage in the near absence of organic inputs to feed on.

Similarly, the reported case above was the exact opposite under Org-Low farming that received minimal organic inputs. The system in return produced rather weak and unhealthy dry maize seedling. These seedlings at the same time portrayed a malnourished maize seedling appeared appealing to termites as preferred feeds between 2 to 7 weeks after emergence. These seedling hence became more pre disposable however to the fewer termites in abundance under the system. Over the period termites significantly devastated, highly lodging the maize seedling ironically by the lower termite population. From the foregoing therefore termites' damage to maize crop do not seem follow the level of termite abundance but on other factors were at play, an observation similar to that by Loko *et al.*, (2017). The later in their argument stated the majority of the termite species associated with crops cannot be directly considered as crop pests and were not equivalent with termite population. Termites' damage to maize cultivars again is largely dependent on crop health status rather than growth stage as was initially believed by Pearce, (1997). The latter in his finding mentioned termites only cause significant damage to mature and not young seedlings a finding which do not concur with the current study. In his finding he believed that termites rarely damaged young seedlings due to their repelling action i.e. the seedling producing phenols and cyanides compounds at that crop stage as from this study termites' ability to destroy dry maize seedlings grown under Org-Low systems were significantly affirmed the few termites in abundance lodging the weakling seedlings. Further still the results affirmed termites' damage to maize as not directly correlated with termite population but other factors were at play.

The other observation from the study revealed baby corn cultivar grown under Conv-High to have recorded the lowest lodging damage except at last harvesting date. The probable reasons for this would the received high inorganic (fertilizer and pesticide) inputs which effectively controlled termite population and lowered maize lodging damage both to the seedling and even maturing plants (i.e. to the end of the trials). By then the toxicity inorganic inputs could have been lost thus resulting in the insignificant damage to the otherwise senescencing maize crop cultivars.

Still from the results usage of pesticide to produce maize seems to be inevitable. For example inorganic Chloropyriphos into Conv-High and botanical fungi icipe isolate 16 (*Metarhizium anisopliae*) into Org-High cannot be avoided completely throughout crop cycle. Cautions however should be taken not to always use “hard” and expensive products but to adopt integrated pest management (IPM) options. If possible the termite control group should always be trained to use among others the botanical *Latana camara*), mineral substances (wood ash, lime), physical queen removal, and mound firing/smoking as listed by Orikiriza *et al.,* (2012); Nyagumbo, *et al.,* (2015).

5.2.3.2 Pestorous termite pests

Under this section the study made effort to identify termites causing damage to maize crops. This subject remains challenging i.e. considering their cryptic nature and secondly due to termites greater appetite feeding and destroying any edible thing along the way. Termite damage is often discovered much later after the damage has occurred usually overnight and it is from there they can be seen swarming (Opiyo *et al.,* 2015). Under the current termite lodging damage were only sampled causing exclusively at Thika site. Field morphological identification of the termites associated with the lodging damage at the site were: *Odontotermes* (*O. somaliensis*), *Macrotermes* (*M. herus* and *M. michaelseni*) and *Pseudacanthotermes* (*P. spiniger* and *P. militaris*). They were found feeding together but members of genera *Odontotermes* were found as modst damaging, them exhibiting aggressive feeding at soil level. When spotted cutting the maize they severally quickly moved below soil surfaces into hiding a characteristic which made their correct identification remaining challenging. Therefore it would be recommended a repeat identification studies in these damaging termite in the future. Also studies on termite tunneling damage could not be conducted into details under the current studies protocol. To successfully do so repeated destructive sampling is recommended and since the trial answer other subject areas (e.g. agronomy and economy) destructive sampling of maize plants was not permit table.

The termite genera associated with tunneling damage symptoms on maize were however *Microtermes*, *Amitermes*, and *Ancistrotermes*. Members of these genera shared some common features and which made them to successfully cause the damage symptoms. These features were smaller size, resident of lower soil profiles, and active crop root-hair penetrator as was similarly stated by Campora and Grace, (2004). The tunneling damage occurred in higher incidence at Chuka than Thika sites. This could be explainable from field observations as connected with excessive flooding there, thus forcing them to reside in deeper soil profiles. Most likely the termites foraged at that soil level from where they caused the tunneling symptoms of damage. Secondly, the higher moisture at Chuka site was hypothesized to prevented termites from freely foraging and constructing foraging tunnels at soil surfaces and instead resided in the deeper soil profiles from where they caused the damage. At the deeper soil profile these termite genera could have also been avoiding the risk of much precipitation and the likelihood of suffocation while constructing runways. At that soil level they caused higher tunneling in the lower soil profile as was similarly found elsewhere by Debelo and Degaga, (2015). In the reverse the lower moisture at Thika site could have influenced higher termite lodging through their aggressive surface foraging at soil surfaces similar observation also reported by Lenz *et al.*, (2003). The other observation from the current study found termite colonies attacking and foraging more over dry spells. Such a weather was more ideal for the termites causing “flash lodging damage” overnight especially to the aging and matured maize. Lastly although it was not directly the subject of data collection the relevance of termite species being an influencing factor causing termite damage, the field observation found termite genera *Odontotermes sp* found exclusively at Thika to cause most lodging damage to maize. The termite genera related with lower rainfall and higher lodging damage recorded at the site were similarly observed causing much damage by Uys, (2002) from other studies elsewhere. Such an observation there affirmed the difference in termite identity as can influence the extent by which termites cause damage on maize crops.

5.3 Conclusions

In conclusion, the study on termite for the first time discovered the possibility enhancing their population in farms through Org-High farming system. This was made possible due to the applied farm inputs initially added to enhance productivity and the changed soil physiochemical properties. The added natural organic inputs included soil compost, manure, crop residues and mulch, coupled with the planted leguminous cover-crop, plus availability of moisture supplied through irrigation during periods of a dry spells. Also some of soil physiochemical properties that underwent changes under the farming system also included soil fractions (i.e. tending towards clayish), enhanced soil moisture retention, and improved chemicals (macro- and micro-) elements. These in turn boosted termite population under the farming system and more so at Chuka site, and even under bean dominated cropping within top-soil profile. Such places favored termite abundance due to available termite fees, ideal cooler climate and clayish soil content, and the created microclimate environment by crop canopies all that supported termite survival and developments.

Secondly under the candidate Org-High farming system, initially chosen for its characteristic to mimic commercial and export-oriented crop production it has proved to be suitable and ideal soil for crop production. Combined with abundant termite population the soil characters there became properly synthesized into organic matter, with higher levels of carbon, and nitrogenous nutrients all synthesized by termites. Such soils even allowed for better crop growth and were even able to support the high-valued crops; such a production been the preserve of large-scale and resourceful farmers. Under this system such high valued crops including baby corn, French beans, cabbages and tomatoes can now be grown by the resource-poor within the tropics for income generation and especially with availability of termites in high population in farms.

The general assessment of termite damaging identified lodging type as the most important on maize cultivars. It affected dry maize cultivar more so at the seedling crop stage thus can compromise crop stand necessitating seedling gapping often at a cost to growers under the Org-Low system. The maize cultivar grown under the system also portrayed a weakly and poorer growth; crop stands that were more a pealing to termites feeds. The lodging type of damage were also noted on baby corn cultivar but at crop maturity to senescence stages. The maize cultivar were least affected at seedling crop due to the vigorous growing and unattractive termite feeds; and the majority termites under the system preferring to feed instead on plenty-received natured organic inputs to the Org-High system. Higher termite lodging damage to baby corn cultivars hence occurred at the crop senescence stage i.e. well past peak harvesting had economically been realized. The peak baby corn harvest occurs between 3rd and 16th harvesting stages, hence any subsequent damage were of least economic importance. Otherwise after peak harvest has occurred it would be advisable that by 10 days an early crop harvest be carried out, utilizing the produce either as animal feeds or stover.

5.4 Recommendations

The following are some of the recommendations from termite studies that compared the influence of farming systems on termite indices:

1. For the first time Org-High farming has provided the road map for promotion and existence of abundant and diversified termite genera. It could be recommended as a vital technology worth training especially to farming community of region on its relevance, i.e. its ability for the first time promoting mass rearing termites by simply regulating types and amount of the natural farm inputs for crop productions.
2. Through the employment of Org-High farming system some vital soil physiochemical properties including: soil fraction, and moisture retention are achievable. Others stand to be altered were chemical elements with Mg K, pH, CEC, and EC found to be most affected after just about seven years. The alteration of these soil properties directly and positively related with termite indices for the betterment of sustainable crop production; chemical such as pH > P(Olsen) > K > Ca and > Mg found to be enhancing termite high population and

foraging activities too. Soils highly dominated by termites also exhibited higher aeration, porousity and improved soil mineralization. The result further promises the possibility enhancing crop production using minimal inorganic chemicals, growing also high valued crops (including baby corn, French beans, cabbages etc) crops which have been the preserve of large scale farmers but could now be grown by small scale and resource poor farmers by just adopting Org-High system. It is recommended subsequent consultative regular soil sampling on the same plots continue to be done. Some of the soil changes to be closely followed should also include bulk density, hydraulic conductivity and on termite abundance at the LTE trials.

3. The high termite population was recognized more associated with the advantages of farm soils and not directly correlated with termite pest damage. The termites least preferred the fresh, green, and vigorous growing plant tissues as feeds to the malnourished, and weakly established maize seedlings and maturing crop stages. Availability of natural organic farm inputs were found to not only produce healthy and vigorous growing plants, but the organic input including crop residues were more preferred by termites as feeds. A proper termite management involving avoidance of the natural input depletion managed termite population; hence termites' high population in farms should not always be viewed as crop pests but as a holistic farming system enhancing sustainable food production.
4. The presence of ants within substrates at Chuka site evokes the advantageos outcome often associated with biological pest control, and its success should be properly assessed. A further study towards that is highly recommended.

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APPENDICES

Appendix I: Treatment details and the cropping pattern of the long-term farming systems comparisons trials at Chuka and Thika, Central Highlands of Kenya (Adamtey et al., 2016, modified)

Farming system	**Year**	**Season**	**Crop (variety)**	**Fertilizer management**	**Total N applied** [kg ha^{-1}]	**Total P applied** [kg ha^{-1}]	**Pest & Disease management**	**Water management**
Conv-Low	2014	LS	Maize (H513)	5 t ha^{-1} of fresh FYM, 50 kg ha^{-1} D	31	18	Synthetic pesticides	Rain fed
		SS	Common beans (GLP92)	No fertilizer application	NA	NA		
	2015	LS	Maize (H513) / common beans (GLP 92)	5 tha^{-1} of fresh FYM, 50 kg ha^{-1} DAP	31	18		
Org-Low	2014	LS	Maize (H513)	5 t ha^{-1} FYM-based compost, 100 kg ha^{-1} RP, 1.36 kg ha^{-1} Tithonia mulch	31	18	No plant protection	Rain fed
		SS	Common beans (GLP92)	No fertilizer application	NA	NA		

Appendix II: The average, standard error of means and sources of variation for average termite abundance, incidence index, tunneling and gallery activity

				Auandance				Incidence				activity	
				Total	Worker	Soldier	Immature	Total	Worker	Soldier	Immature	Tunnelling	Gallery
				Mean sem	Mean sem	Mean sem	Mean sem	Mean sem	Mean sem	Mean sem	Mean sem	Mean sem	Mean sem
Chuka	1st season	Substrate	Conv-Low	0.46±0.17	0.02±0.02	0.00 ±0.00	0.44±0.16	0.31 ±0.10	0.02 ±0.02	0.00 ±0.00	0.31 ±0.10	1.78±0.18	NA
			Org-Low	0.19±0.17	0.02±0.02	0.00 ±0.00	0.17±0.15	0.10 ±0.08	0.02 ±0.02	0.00 ±0.00	0.10 ±0.08	1.51±0.17	NA
			Conv-High	1.33±0.80	0.23±0.14	0.10 ±0.10	1.00±0.58	0.31 ±0.13	0.19 ±0.11	0.08 ±0.08	0.31 ±0.13	1.61±0.13	NA
			Org-High	15.50±2.46	2.44±0.42	1.33 ±0.25	11.73±1.82	2.33 ±0.25	1.63 ±0.24	1.06 ±0.19	2.33 ±0.25	14.72±1.36	NA
Chuka	1st season	Topsoil	Conv-Low	5.70±0.88	0.89±0.16	0.32 ±0.08	4.49±0.66	1.55 ±0.15	0.77 ±0.12	0.26 ±0.06	1.55 ±0.15	NA	6.80±1.25
			Org-Low	4.44±0.83	0.63±0.15	0.28 ±0.07	3.53±0.63	1.22 ±0.14	0.45 ±0.09	0.22 ±0.05	1.20 ±0.13	NA	3.27±0.29
			Conv-High	5.63±0.83	0.85±0.15	0.36 ±0.09	4.43±0.61	1.60 ±0.16	0.77 ±0.12	0.34 ±0.08	1.60 ±0.16	NA	6.09±0.57
			Org-High	32.88 ±2.70	5.21±0.43	3.45 ±0.31	24.21±1.99	3.03 ±0.15	2.67 ±0.16	2.20 ±0.15	2.99 ±0.15	NA	45.45±5.51
Chuka	1st season	Subsoil	Conv-Low	5.17±0.78	0.72±0.14	0.33 ±0.10	4.13±0.56	1.59 ±0.15	0.63 ±0.11	0.26 ±0.07	1.59 ±0.15	NA	5.64±1.31
			Org-Low	4.40±0.73	0.59±0.13	0.33 ±0.09	3.49±0.54	1.43 ±0.14	0.51 ±0.10	0.27 ±0.07	1.39 ±0.14	NA	2.10±0.21
			Conv-High	4.27±0.69	0.60±0.13	0.23 ±0.07	3.44±0.51	1.45 ±0.15	0.54 ±0.11	0.21 ±0.06	1.44 ±0.15	NA	3.33±0.33
			Org-High	28.25 ±2.75	4.62±0.44	2.79 ±0.28	20.85±2.05	2.85 ±0.16	2.52 ±0.16	1.93 ±0.16	2.78 ±0.17	NA	24.57±3.47
Chuka	2nd season	Substrate	Conv-Low	5.83±2.25	1.00±0.40	0.35 ±0.12	4.48±1.77	0.88 ±0.22	0.58 ±0.19	0.30 ±0.10	0.80 ±0.22	3.41±0.63	NA
			Org-Low	4.05±1.79	0.58±0.30	0.20 ±0.11	3.28±1.41	0.83 ±0.22	0.35 ±0.16	0.18 ±0.09	0.78 ±0.22	4.48±0.87	NA
			Conv-High	3.48±1.50	0.55±0.26	0.18 ±0.11	2.75±1.19	0.75 ±0.20	0.43 ±0.17	0.18 ±0.11	0.70 ±0.20	4.76±0.86	NA
			Org-High	43.98±6.84	7.58±1.19	1.40 ±0.23	35.00±5.58	3.78 ±0.07	3.23 ±0.17	1.28 ±0.20	3.78 ±0.07	41.74±2.87	NA
Chuka	2nd season	Topsoil	Conv-Low	10.30±1.41	1.69±0.26	0.59 ±0.13	8.03±1.09	2.20 ±0.19	1.38 ±0.19	0.56 ±0.12	2.06 ±0.19	NA	10.89±3.13
			Org-Low	7.48±1.27	1.14±0.24	0.53 ±0.13	5.81±1.00	1.93 ±0.16	0.88 ±0.15	0.45 ±0.10	1.73 ±0.16	NA	5.71±0.55
			Conv-High	12.85±1.66	1.90±0.30	0.94 ±0.19	10.01±1.31	2.55 ±0.17	1.38 ±0.18	0.76 ±0.14	2.40 ±0.18	NA	12.38±3.21
			Org-High	70.43±4.10	11.78±0.69	3.58 ±0.34	55.08±3.36	3.96 ±0.03	3.83 ±0.07	2.38 ±0.15	3.96 ±0.03	NA	83.69±5.18
Chuka	2nd season	Subsoil	Conv-Low	7.51 ±1.37	1.16±0.23	0.41 ±0.10	5.94±1.07	1.65 ±0.18	0.94 ±0.16	0.39 ±0.09	1.59 ±0.19	NA	7.00±2.89
			Org-Low	3.31 ±0.68	0.46±0.12	0.20 ±0.06	2.65±0.54	1.24 ±0.15	0.43 ±0.10	0.20 ±0.06	1.10 ±0.14	NA	2.69±0.28
			Conv-High	10.10±1.47	1.64±0.27	0.53 ±0.12	7.94±1.14	2.16 ±0.18	1.25 ±0.18	0.50 ±0.11	2.08±0.18	NA	8.08±2.25
			Org-High	54.96±4.28	9.26±0.76	2.66 ±0.27	43.04±3.49	3.88 ±0.05	3.59 ±0.10	2.01 ±0.16	3.86±0.06	NA	41.20±4.18
Chuka	3rd season	Substrate	Conv-Low	2.30±1.04	0.36±0.18	0.06 ±0.03	1.88±0.84	0.44 ±0.13	0.22 ±0.09	0.06 ±0.03	0.41±0.12	1.11±0.26	NA
			Org-Low	2.22±0.89	0.38±0.16	0.09 ±0.04	1.75±0.70	0.41 ±0.14	0.27 ±0.10	0.09 ±0.04	0.41±0.14	0.94±0.14	NA
			Conv-High	1.23±0.44	0.20±0.09	0.09 ±0.08	0.94±0.35	0.42 ±0.13	0.20 ±0.09	0.08 ±0.06	0.36±0.12	1.11±0.19	NA
			Org-High	14.86±3.88	2.53±0.68	0.80 ±0.14	11.53±3.16	2.02 ±0.19	1.22 ±0.21	0.72 ±0.12	1.63±0.21	47.63±2.19	NA
Chuka	3rd season	Topsoil	Conv-Low	5.91±1.01	0.99±0.18	0.35 ±0.08	4.56±0.77	1.12 ±0.12	0.66 ±0.11	0.29 ±0.06	1.04±0.12	NA	8.59±2.33
			Org-Low	6.45±1.15	1.04±0.20	0.36 ±0.08	5.05±0.89	1.32 ±0.13	0.68 ±0.11	0.33 ±0.07	1.26±0.13	NA	5.09±0.48
			Conv-High	3.30±0.63	0.48±0.11	0.24 ±0.05	2.58±0.50	0.94 ±0.11	0.43 ±0.09	0.23 ±0.05	0.82±0.11	NA	4.08±1.72

			Org-High	*35.91±3.35*	*5.79±0.58*	*2.66 ±0.21*	*27.47±2.67*	*3.37 ±0.09*	*2.39 ±0.15*	*1.88 ±0.12*	*3.04±0.12*	*NA*	*64.06±10.38*
Chuka	*3rd season*	*Subsoil*	*Conv-Low*	*5.73±1.18*	*0.92±0.20*	*0.27±0.06*	*4.54±0.94*	*1.13 ±0.13*	*0.60 ±0.11*	*0.25 ±0.06*	*1.05±0.13*	*NA*	*6.20±2.12*
			Org-Low	*6.31±0.96*	*1.07±0.18*	*0.38 ±0.07*	*4.86±0.73*	*1.36 ±0.13*	*0.80 ±0.11*	*0.34 ±0.06*	*1.26±0.13*	*NA*	*3.14±0.33*
			Conv-High	*4.02±0.68*	*0.66±0.13*	*0.26 ±0.05*	*3.09±0.52*	*0.97 ±0.12*	*0.54 ±0.10*	*0.25 ±0.05*	*0.90±0.12*	*NA*	*3.09±1.2*
			Org-High	*28.77±2.41*	*4.86±0.42*	*2.11 ±0.20*	*21.80±1.89*	*3.19 ±0.11*	*2.50 ±0.15*	*1.53 ±0.12*	*2.93±0.13*	*NA*	*20.13±5.36*
Thika	*1st season*	*Substrate*	*Conv-Low*	*3.42±1.4*	*0.56±0.25*	*0.34 ±0.12*	*2.52±1.07*	*0.66 ±0.18*	*0.42 ±0.17*	*0.32 ±0.11*	*0.54±0.19*	*1.72±0.33*	*NA*
			Org-Low	*2.46±1.13*	*0.42±0.21*	*0.34 ±0.09*	*1.70±0.87*	*0.60 ±0.16*	*0.30 ±0.14*	*0.32 ±0.08*	*0.36±0.15*	*1.91±0.43*	*NA*
			Conv-High	*2.70±1.00*	*0.44±0.18*	*0.36 ±0.12*	*1.90±0.76*	*0.70 ±0.18*	*0.32 ±0.13*	*0.30 ±0.09*	*0.50±0.17*	*1.97±0.48*	*NA*
			Org-High	*16.40±3.34*	*2.52±0.54*	*2.72 ±0.46*	*11.16±2.46*	*2.04 ±0.25*	*1.50 ±0.27*	*1.64 ±0.20*	*1.68±0.26*	*51.47±7.74*	*NA*
Thika	*1st season*	*Topsoil*	*Conv-Low*	*1.84±0.71*	*0.21±0.12*	*0.14 ±0.04*	*1.49±0.58*	*0.46 ±0.12*	*0.13 ±0.06*	*0.14 ±0.04*	*0.39±0.11*	*NA*	*2.30±0.27*
			Org-Low	*3.66±0.82*	*0.56±0.16*	*0.56 ±0.09*	*2.54±0.64*	*1.07 ±0.14*	*0.43 ±0.11*	*0.53 ±0.08*	*0.66±0.14*	*NA*	*2.18±0.26*
			Conv-High	*3.51±0.92*	*0.53±0.17*	*0.26 ±0.08*	*2.72±0.73*	*0.77 ±0.14*	*0.39 ±0.12*	*0.25 ±0.07*	*0.67±0.14*	*NA*	*7.12±0.47*
			Org-High	*9.29±1.38*	*1.16±0.24*	*2.67 ±0.29*	*5.46±0.97*	*2.11 ±0.17*	*0.82 ±0.15*	*1.70 ±0.15*	*1.36±0.18*	*NA*	*31.95±3.62*
Thika	*1st season*	*Subsoil*	*Conv-Low*	*0.54±0.39*	*0.09±0.08*	*0.03 ±0.02*	*0.42±0.29*	*0.12 ±0.06*	*0.05 ±0.04*	*0.03 ±0.02*	*0.11±0.06*	*NA*	*0.24±0.09*
			Org-Low	*0.79±0.3*	*0.15±0.07*	*0.01 ±0.01*	*0.63±0.23*	*0.27 ±0.09*	*0.15 ±0.07*	*0.01 ±0.01*	*0.26±0.09*	*NA*	*0.16±0.06*
			Conv-High	*0.90±0.39*	*0.13±0.07*	*0.02 ±0.01*	*0.75±0.31*	*0.23 ±0.08*	*0.10 ±0.06*	*0.02 ±0.01*	*0.23±0.08*	*NA*	*2.05±0.23*
			Org-High	*2.96±0.82*	*0.37±0.14*	*0.82 ±0.17*	*1.77±0.56*	*0.79 ±0.14*	*0.30 ±0.10*	*0.63 ±0.11*	*0.48±0.12*	*NA*	*5.15±2.08*
Thika	*2nd season*	*Substrate*	*Conv-Low*	*2.91±1.49*	*0.43±0.29*	*0.34 ±0.11*	*2.14±1.13*	*0.69 ±0.21*	*0.23 ±0.16*	*0.34 ±0.11*	*0.49±0.20*	*3.63±1.25*	*NA*
			Org-Low	*4.54±2.07*	*0.74±0.34*	*0.29 ±0.13*	*3.51±1.65*	*0.80 ±0.23*	*0.49 ±0.21*	*0.26 ±0.10*	*0.66±0.24*	*5.28±1.53*	*NA*
			Conv-High	*5.86±1.68*	*1.03±0.34*	*0.31 ±0.11*	*4.51±1.32*	*1.26 ±0.27*	*0.74 ±0.23*	*0.29 ±0.10*	*1.09±0.28*	*5.79±1.79*	*NA*
			Org-High	*88.77±11.4*	*14.57±1.94*	*6.17 ±0.48*	*68.03±9.29*	*3.80 ±0.11*	*3.54 ±0.22*	*3.17 ±0.15*	*3.63±0.19*	*282.33±20.95*	*NA*
Thika	*2nd season*	*Topsoil*	*Conv-Low*	*2.63±0.96*	*0.37±0.16*	*0.30 ±0.08*	*1.96±0.75*	*0.66 ±0.15*	*0.30 ±0.12*	*0.29 ±0.07*	*0.50±0.15*	*NA*	*2.16±0.41*
			Org-Low	*3.26±1.28*	*0.44±0.22*	*0.50 ±0.12*	*2.31±1.02*	*0.87 ±0.17*	*0.24 ±0.10*	*0.46 ±0.10*	*0.50±0.14*	*NA*	*1.51±0.38*
			Conv-High	*6.07±1.36*	*1.03±0.26*	*0.43 ±0.10*	*4.61±1.07*	*1.39 ±0.19*	*0.77 ±0.19*	*0.40 ±0.09*	*1.14±0.19*	*NA*	*5.44±0.86*
			Org-High	*31.01±3.59*	*4.81±0.61*	*4.01 ±0.36*	*22.19±2.80*	*3.51 ±0.14*	*2.53 ±0.21*	*2.50 ±0.16*	*3.16±0.18*	*NA*	*56.51±4.28*
Thika	*2nd season*	*Subsoil*	*Conv-Low*	*0.76±0.28*	*0.06±0.06*	*0.09 ±0.04*	*0.61±0.24*	*0.37 ±0.11*	*0.06 ±0.06*	*0.07 ±0.03*	*0.30±0.11*	*NA*	*0.34±0.14*
			Org-Low	*0.10±0.05*	*0.00±0.00*	*0.09 ±0.04*	*0.01±0.01*	*0.10 ±0.05*	*0.00 ±0.00*	*0.09 ±0.04*	*0.01±0.01*	*NA*	*0.01±0.01*
			Conv-High	*1.33±0.48*	*0.19±0.09*	*0.04 ±0.02*	*1.10±0.39*	*0.44 ±0.13*	*0.19 ±0.09*	*0.04 ±0.02*	*0.41±0.13*	*NA*	*1.30±0.24*
			Org-High	*8.04±1.62*	*1.36±0.29*	*1.17 ±0.22*	*5.51±1.17*	*1.63 ±0.21*	*1.03 ±0.20*	*0.96 ±0.15*	*1.31±0.22*	*NA*	*5.51±1.12*
Thika	*3rd season*	*Substrate*	*Conv-Low*	*1.15±0.42*	*0.11 ±0.07*	*0.18 ±0.05*	*0.86±0.36*	*0.48 ±0.13*	*0.11 ±0.07*	*0.18 ±0.05*	*0.32±0.13*	*1.37±0.3*	*NA*
			Org-Low	*4.02±1.21*	*0.69 ±0.22*	*0.25 ±0.07*	*3.08±0.95*	*0.89 ±0.18*	*0.54 ±0.16*	*0.25 ±0.07*	*0.77±0.18*	*2.83±0.54*	*NA*
			Conv-High	*1.00±0.45*	*0.15 ±0.10*	*0.22 ±0.06*	*0.63±0.36*	*0.42 ±0.11*	*0.12 ±0.07*	*0.22 ±0.06*	*0.20±0.10*	*1.16±0.27*	*NA*
			Org-High	*47.63±7.83*	*7.49 ±1.28*	*4.49 ±0.50*	*35.65±6.13*	*3.02 ±0.17*	*2.25 ±0.24*	*2.49 ±0.16*	*2.52±0.23*	*108.74±6.42*	*NA*
Thika	*3rd season*	*Topsoil*	*Conv-Low*	*1.43±0.52*	*0.22 ±0.09*	*0.16 ±0.04*	*1.05±0.41*	*0.41 ±0.09*	*0.18 ±0.07*	*0.15 ±0.04*	*0.30±0.09*	*NA*	*2.85±0.42*
			Org-Low	*6.10±1.37*	*1.03 ±0.23*	*0.38 ±0.09*	*4.69±1.06*	*1.08 ±0.14*	*0.70 ±0.12*	*0.32 ±0.07*	*0.98±0.14*	*NA*	*5.02±1.12*

			Conv-High	2.64±0.95	0.45 ±0.17	0.34 ±0.07	1.85±0.74	0.55 ±0.10	0.28 ±0.08	0.32 ±0.06	0.35±0.09	NA	3.12±0.54
			Org-High	30.67±3.61	4.95 ±0.58	3.25 ±0.34	22.47±2.73	2.65 ±0.15	2.13 ±0.16	1.78 ±0.13	2.44±0.16	NA	59.96±4.2
Thika	3rd season	Subsoil	Conv-Low	0.75 ±0.42	0.06 ±0.04	0.07 ±0.03	0.62±0.37	0.14 ±0.06	0.05 ±0.03	0.06 ±0.02	0.11±0.05	NA	0.24±0.09
			Org-Low	0.41 ±0.17	0.08 ±0.04	0.01 ±0.01	0.32±0.14	0.14 ±0.05	0.08 ±0.04	0.01 ±0.01	0.13±0.05	NA	0.30±0.08
			Conv-High	0.78 ±0.37	0.15 ±0.07	0.03 ±0.02	0.61±0.29	0.17 ±0.07	0.12 ±0.05	0.03 ±0.02	0.15±0.06	NA	0.86±0.18
			Org-High	8.87 ±1.85	1.45 ±0.31	0.93 ±0.17	6.49±1.38	1.12 ±0.15	0.74 ±0.13	0.63 ±0.10	1.02±0.15	NA	11.20±2.46
Source of variation for substrate													
Farming system				***	***	***	***	***	***	***	***	***	Na
Season				***	***	***	***	***	***	***	***	***	Na
Site				**	**	***	**	*	**	***	ns	***	Na
Farming system x season				***	***	***	***	***	***	***	***	***	Na
Farming system x site				***	***	***	***	ns	Ns	***	ns	***	Na
Farming system x site x season				***	***	***	***	**	**	***	***	***	Na
Source of variation for soil													
Farming system				***	***	***	***	***	***	***	***	na	***
Depth				***	***	***	***	***	***	***	***	na	***
Season				***	***	***	***	***	***	***	***	na	***
Site				***	***	**	***	***	***	***	***	na	**
Farming system x depth				***	***	***	***	***	***	***	***	na	***
Farming system x season				***	***	*	***	***	***	***	***	na	***
Farming system x site				***	***	***	***	***	***	***	***	na	***
Farming system x depth x season				**	**	ns	**	ns	Ns	ns	ns	na	***
Farming system x site x depth				*	*	***	ns	***	***	***	***	na	Ns
Farming system x site x season				***	***	***	***	**	***	***	ns	na	**
Farming system x depth x season x site				Ns	Ns	ns	ns	ns	*	ns	*	na	Ns

Legend: total number of termites and termite caste in in the substrate, top- and subsoil and in organic and conventional farming systems in the farming systems comparisons trials at Chuka and Thika, the Central Highlands of Kenya; na, not applicable; ns, not significant;

NB: Significant differences between farming system, site, season, depth or their interactions are indicated by * ($p < 0.05$), ** ($p <0.01$) or *** ($p < 0.001$); Specifications (fixed and random factors) of the linear model can be found in the chapter

Appendix III: Average values per treatment and source of variation for species richness (S), the incidence-based coverage estimator of species richness (ICE), the Chao2 estimator of species richness, and the Shannon index (Sh) and inverse Simpson index (Si) in the top- and subsoil (top) and in the substrate (bottom) in organic and conventional

				S		**ICE**		**Chao2**		**S_h**		**S_i**	
				Mean	sem	Mean	sem	Mean	sem	Mean	Sem	Mean	Sem
Chuka	1st season	Substrate	Conv-Low	0.66	±0.04	0.66	±0.04	0.66	±0.04	0.00	±0.00	1.00	±0.00
			Org-Low	0.54	±0.06	0.51	±0.06	0.51	±0.06	0.01	±0.00	1.02	±0.00
			Conv-High	1.00	±0.13	1.68	±0.33	1.68	±0.33	0.30	±0.07	1.50	±0.12
			Org-High	4.32	±0.19	6.47	±0.28	4.87	±0.2	0.97	±0.03	2.11	±0.04
Chuka	1st season	Topsoil	Conv-Low	2.73	±0.16	4.47	±0.25	3.06	±0.16	0.54	±0.04	1.53	±0.05
			Org-Low	3.26	±0.17	6.55	±0.33	4.45	±0.25	0.69	±0.03	1.65	±0.03
			Conv-High	2.83	±0.13	4.29	±0.22	3.05	±0.14	0.58	±0.04	1.59	±0.06
			Org-High	6.84	±0.17	8.32	±0.25	7.57	±0.21	1.57	±0.02	4.09	±0.04
Chuka	1st season	Subsoil	Conv-Low	3.61	±0.25	8.49	±1.00	5.93	±0.77	0.61	±0.03	1.54	±0.03
			Org-Low	3.63	±0.27	6.74	±0.51	4.66	±0.40	0.63	±0.05	1.60	±0.06
			Conv-High	2.71	±0.12	5.02	±0.29	3.34	±0.18	0.47	±0.02	1.40	±0.02
			Org-High	6.92	±0.22	8.95	±0.32	7.91	±0.24	1.56	±0.03	4.02	±0.08
Chuka	2nd season	Substrate	Conv-Low	2.06	±0.20	3.12	±0.33	2.44	±0.24	0.63	±0.05	1.79	±0.07
			Org-Low	1.60	±0.17	2.97	±0.50	2.65	±0.51	0.42	±0.07	1.61	±0.12
			Conv-High	1.29	±0.10	1.84	±0.20	1.62	±0.19	0.32	±0.04	1.34	±0.04
			Org-High	4.02	±0.15	6.35	±0.27	4.62	±0.17	0.81	±0.02	1.77	±0.02
Chuka	2nd season	Topsoil	Conv-Low	3.45	±0.21	7.03	±0.55	4.73	±0.37	0.72	±0.04	1.76	±0.05
			Org-Low	2.99	±0.15	5.62	±0.42	3.70	±0.23	0.65	±0.03	1.63	±0.02
			Conv-High	3.81	±0.20	7.69	±0.51	5.37	±0.41	0.79	±0.04	1.86	±0.04
			Org-High	6.12	±0.15	7.35	±0.24	6.32	±0.15	1.50	±0.02	3.75	±0.07
Chuka	2nd season	Subsoil	Conv-Low	3.53	±0.20	8.95	±0.70	5.45	±0.39	0.74	±0.04	1.79	±0.06
			Org-Low	2.29	±0.14	4.43	±0.46	2.74	±0.22	0.42	±0.03	1.38	±0.03
			Conv-High	3.31	±0.19	6.39	±0.56	4.44	±0.37	0.71	±0.03	1.72	±0.04
			Org-High	6.35	±0.15	7.83	±0.36	6.57	±0.15	1.48	±0.03	3.47	±0.08
Chuka	3rd season	Substrate	Conv-Low	1.21	±0.09	1.73	±0.18	1.34	±0.10	0.25	±0.03	1.27	±0.03
			Org-Low	1.43	±0.11	2.71	±0.39	1.91	±0.19	0.41	±0.03	1.40	±0.03
			Conv-High	1.02	±0.08	1.44	±0.19	1.19	±0.12	0.17	±0.04	1.23	±0.05
			Org-High	3.72	±0.16	6.18	±0.37	4.29	±0.22	0.83	±0.02	1.91	±0.03

Chuka	3rd season	Topsoil	Conv-Low	3.35 ±0.14	5.89 ±0.26	4.05 ±0.16	0.77 ±0.02	1.86 ±0.04
			Org-Low	3.18 ±0.16	5.05 ±0.31	3.93 ±0.25	0.70 ±0.03	1.75 ±0.04
			Conv-High	3.11 ±0.14	5.19 ±0.27	3.94 ±0.20	0.70 ±0.02	1.72 ±0.02
			Org-High	6.89 ±0.18	8.96 ±0.22	7.56 ±0.18	1.48 ±0.02	3.51 ±0.04
Chuka	3rd season	Subsoil	Conv-Low	3.05 ±0.16	6.73 ±0.50	4.36 ±0.28	0.67 ±0.02	1.65 ±0.02
			Org-Low	4.34 ±0.18	8.00 ±0.39	5.31 ±0.22	0.89 ±0.03	1.95 ±0.05
			Conv-High	3.42 ±0.16	7.05 ±0.43	4.94 ±0.27	0.77 ±0.02	1.80 ±0.02
			Org-High	6.78 ±0.18	8.72 ±0.25	7.33 ±0.18	1.46 ±0.02	3.35 ±0.04
Thika	1st season	Substrate	Conv-Low	1.86 ±0.17	4.03 ±0.50	3.26 ±0.46	0.68 ±0.07	1.96 ±0.11
			Org-Low	1.61 ±0.16	2.40 ±0.30	1.82 ±0.19	0.47 ±0.06	1.63 ±0.08
			Conv-High	1.79 ±0.22	3.20 ±0.55	2.34 ±0.36	0.43 ±0.07	1.69 ±0.12
			Org-High	4.34 ±0.20	6.23 ±0.34	5.02 ±0.22	1.21 ±0.03	3.12 ±0.08
Thika	1st season	Topsoil	Conv-Low	1.66 ±0.14	2.59 ±0.29	1.88 ±0.17	0.44 ±0.05	1.51 ±0.06
			Org-Low	2.73 ±0.15	4.18 ±0.25	3.19 ±0.21	0.74 ±0.04	1.93 ±0.07
			Conv-High	2.20 ±0.25	3.74 ±0.50	2.93 ±0.42	0.52 ±0.06	1.66 ±0.09
			Org-High	4.48 ±0.18	6.04 ±0.28	4.92 ±0.2	1.24 ±0.03	3.21 ±0.08
Thika	1st season	Subsoil	Conv-Low	1.16 ±0.20	2.28 ±0.59	1.51 ±0.31	0.28 ±0.07	1.33 ±0.09
			Org-Low	0.89 ±0.07	1.00 ±0.10	0.93 ±0.08	0.07 ±0.02	1.06 ±0.02
			Conv-High	0.88 ±0.09	1.30 ±0.25	0.97 ±0.12	0.14 ±0.04	1.13 ±0.04
			Org-High	3.55 ±0.19	6.95 ±0.63	5.28 ±0.35	1.20 ±0.03	3.12 ±0.08
Thika	2nd season	Substrate	Conv-Low	1.60 ±0.18	2.50 ±0.36	2.04 ±0.27	0.57 ±0.07	1.79 ±0.10
			Org-Low	1.58 ±0.20	3.37 ±0.78	2.39 ±0.41	0.46 ±0.06	1.56 ±0.08
			Conv-High	1.69 ±0.18	2.65 ±0.37	1.94 ±0.22	0.40 ±0.06	1.46 ±0.07
			Org-High	5.31 ±0.17	6.79 ±0.29	5.78 ±0.2	1.34 ±0.03	3.31 ±0.07
Thika	2nd season	Topsoil	Conv-Low	2.40 ±0.26	3.75 ±0.50	2.79 ±0.31	0.69 ±0.07	1.93 ±0.11
			Org-Low	2.34 ±0.23	4.00 ±0.50	2.81 ±0.29	0.68 ±0.06	1.90 ±0.10
			Conv-High	2.91 ±0.18	5.55 ±0.54	3.72 ±0.31	0.74 ±0.05	1.92 ±0.12
			Org-High	5.67 ±0.20	7.26 ±0.36	5.94 ±0.22	1.43 ±0.03	3.65 ±0.08
Thika	2nd season	Subsoil	Conv-Low	1.56 ±0.16	2.26 ±0.30	1.77 ±0.20	0.42 ±0.04	1.43 ±0.04
			Org-Low	0.57 ±0.08	0.56 ±0.08	0.56 ±0.08	0.01 ±0.00	1.01 ±0.00
			Conv-High	1.14 ±0.13	1.61 ±0.23	1.20 ±0.13	0.18 ±0.03	1.14 ±0.03
			Org-High	3.93 ±0.24	6.11 ±0.43	4.68 ±0.29	1.05 ±0.04	2.55 ±0.09
Thika	3rd season	Substrate	Conv-Low	1.42 ±0.10	2.26 ±0.24	1.68 ±0.13	0.47 ±0.04	1.66 ±0.06
			Org-Low	2.29 ±0.15	4.38 ±0.37	3.09 ±0.23	0.58 ±0.04	1.66 ±0.07
			Conv-High	1.10 ±0.07	1.38 ±0.11	1.15 ±0.08	0.26 ±0.03	1.33 ±0.04
			Org-High	5.43 ±0.12	6.59 ±0.19	5.77 ±0.12	1.43 ±0.02	3.66 ±0.06

Thika	3rd season	Topsoil	Conv-Low	2.25 ±0.16	3.39 ±0.27	2.80 ±0.20	0.66 ±0.03	1.80 ±0.05
			Org-Low	3.26 ±0.19	5.90 ±0.40	4.17 ±0.26	0.76 ±0.04	1.86 ±0.06
			Conv-High	2.54 ±0.19	4.70 ±0.65	3.31 ±0.36	0.69 ±0.06	2.14 ±0.13
			Org-High	6.11 ±0.12	7.19 ±0.19	6.41 ±0.12	1.53 ±0.02	3.99 ±0.06
Thika	3rd season	Subsoil	Conv-Low	1.60 ±0.16	3.46 ±0.59	2.72 ±0.36	0.61 ±0.07	1.72 ±0.09
			Org-Low	0.72 ±0.06	0.81 ±0.08	0.76 ±0.07	0.07 ±0.02	1.08 ±0.02
			Conv-High	1.37 ±0.14	2.53 ±0.36	2.00 ±0.24	0.45 ±0.05	1.61 ±0.09
			Org-High	4.71 ±0.20	7.70 ±0.29	5.81 ±0.19	1.25 ±0.02	2.99 ±0.06
			Source of variation for substrate					
			Farming system	***	***	***	***	***
			Season	***	Ns	*	ns	Ns
			Site	***	Ns	*	***	**
			Farming system x season	Ns	Ns	Ns	ns	Ns
			Farming system x site	Ns	Ns	Ns	ns	***
			Source of variation for soil					
			Farming system	***	***	***	***	***
			Depth	***	Ns	*	***	***
			Season	**	Ns	Ns	**	Ns
			Site	**	**	**	*	Ns
			Farming system x depth	Ns	**	*	**	Ns
			Farming system x season	*	*	*	ns	Ns
			Farming system x site	ns	***	Ns	ns	Ns

ns, not significant NB: Significant differences between farming system, site, season, depth or their interactions are indicated by * ($p < 0.05$), ** ($p < 0.01$) or *** ($p < 0.001$); Specifications (fixed and random factors) of the linear model can be found in the chapter “Methods”

Appendix IV: Summary raw data Abundance of termite castles and genera found in the long-term farming systems comparisons trial sites at Chuka and Thika in the Central Highlands of Kenya

		Chuka													**Thika**												
			Castle			Genera										Castle			Genera								
1st	Substrate	909	694	141	74	1	0	1	11	27	24	0	10	0	1'249	864	197	188	0	2	0	14	80	43	32	16	1
	0 – 10 cm	2'291	1’733	352	206	4	1	4	35	77	64	0	20	1	1'061	667	150	244	0	0	0	6	66	115	43	14	0
	10 – 20 cm	2'769	2’080	437	252	10	9	10	36	85	82	0	19	1	769	554	96	119	0	5	0	11	34	54	6	7	2
	20 – 30 cm	2'448	1’863	378	207	6	18	6	17	70	68	0	19	3	445	313	66	66	0	2	0	6	27	16	6	9	0
	30 – 40 cm	1'930	1’455	300	175	4	14	4	16	54	61	0	15	7	74	44	8	22	0	4	0	2	3	11	0	2	0
	Total	**10'347**	**7’825**	**1’608**	**914**	**25**	**42**	**25**	**115**	**313**	**299**	**0**	**83**	**12**	**3'598**	**2’442**	**517**	**639**	**0**	**13**	**0**	**39**	**210**	**239**	**87**	**48**	**3**
2nd	Substrate	2'293	1’820	388	85	0	0	0	12	28	28	0	17	0	3'573	2’737	587	249	0	1	0	36	126	25	44	16	1
	0 – 10 cm	4'315	3’371	700	244	0	1	0	32	61	105	0	34	11	1'800	1’301	275	224	0	0	0	26	60	81	38	13	6
	10 – 20 cm	3'769	2’943	620	206	0	2	0	32	50	75	0	32	15	1'208	874	191	143	0	1	0	23	47	45	18	2	7
	20 – 30 cm	3'426	2’689	564	173	0	18	0	17	36	55	0	32	15	520	369	88	63	0	3	0	7	25	16	8	1	3
	30 – 40 cm	2'645	2’076	438	131	0	13	0	14	17	47	0	22	18	196	138	24	34	0	4	0	6	10	11	0	0	3
	Total	**16'448**	**12’899**	**2’710**	**839**	**0**	**34**	**0**	**107**	**192**	**310**	**0**	**137**	**59**	**7'297**	**5’419**	**1’165**	**713**	**0**	**9**	**0**	**98**	**268**	**178**	**108**	**32**	**20**
3rd	Substrate	1'319	1’030	222	67	1	1	1	8	27	16	0	13	0	3'497	2’614	549	334	0	2	0	33	137	36	70	56	0
	0 – 10 cm	3'209	2’469	510	230	6	3	6	34	83	68	0	15	15	3'292	2’423	527	342	0	0	0	40	97	104	66	32	3
	10 – 20 cm	3'393	2’608	553	232	1	4	0	39	89	66	0	17	16	2'017	1’486	336	195	0	4	0	15	57	54	34	23	8
	20 – 30 cm	2'830	2’151	478	201	2	28	3	24	71	48	0	8	17	989	735	155	99	0	7	0	6	28	25	12	15	6
	30 – 40 cm	2'908	2’238	484	186	2	18	1	26	54	51	0	13	21	417	311	70	36	0	4	0	2	15	11	0	3	1
	Total	**13'659**	**10’496**	**2’247**	**916**	**12**	**54**	**11**	**131**	**324**	**249**	**0**	**66**	**69**	**10'212**	**7’569**	**1’637**	**1'006**	**0**	**17**	**0**	**96**	**334**	**230**	**182**	**129**	**18**
	Grand Total	**40'454**	**31’220**	**6’565**	**2'669**	**37**	**130**	**36**	**353**	**829**	**858**	**0**	**286**	**140**	**21'107**	**15’430**	**3’319**	**2'358**	**0**	**39**	**0**	**233**	**812**	**647**	**377**	**209**	**41**

Appendix Va: Summary analyzed data on soil physical properties

	Bulk density		**Hydraulic Cond**		**Moisture retention**		**Wilting point**		**Soil fraction/ Wet sieve**	
Site effect	Chuka	Thika	Chuka	Thika	Chuka	Thika	Chuka	Thika	Chuka	**Thika**
	0.93	0.95	0.04	0.033	28.16 B	31.19 A	22.44 A	22.07 B	0.244 A	**0.145 B**
P- value	0.17ns		0.78ns		0.0001***		0.002**		**0.0001*****	
Farming system effect										
Conv-High	0.92	0.94	0.03	0.022	24.9	32.3	22.03	23.03	0.225	**0.152**
Org-High	0.94	0.97	0.03	0.054	25.2	28.69	22.27	23.17	0.273	**0.132**
Conv-Low	0.9	0.95	0.03	0.034	23.1	34.03	23.03	22.95	0.232	**0.137**
Org-Low	0.95	0.97	0.05	0.022	23.4	29.74	22.43	22.74	0.196	**0.161**
P- value	0.42ns		0.31ns		0.59ns		0.27ns		**0.03***	
Depth effect										
Top soil	0.91 Bb	0.92 Ab	0.047 Aa	0.047 Aa	24.5	39.09	22.37	22.93		
Sub soil	0.95 Ba	0.99 Aa	0.022 Ab	0.019 Bb	26.5	24.46	22.52	23.93		
P- value	0.002**		0.0001***		0.11ns		0.48ns			
Correlation coefficient										
R	-0.1		0.25		-0.183		-0.158		**0.51**	
P	0.41		0.047*		0.012		0.0186		**0.001****	

Appendix Vb: Summary analyzed data on soil chemical properties

	Macronutrients												Exchangeable cations					
	Ca		K		Mg		C		N		P(O)		CEC		EC		pH	
Farming systems																		
Conv High	1544	±86	560	±42	266	±10.1	2.25	±0.09	0.18	±0.01	47	±3.7	19.03	±0.65	170	±16	5.6	±0.06
Org High	2205	±96	502	±45	346	±10	2.4	±0.08	0.19	±0.01	42	±3.4	20	±0.48	232	±9	6.5	±0.09
Conv Low	1414	±112	530	±51	252	±8.5	2.22	±0.09	0.17	±0.01	26	±2.9	16.9	±0.54	112	±10	5.5	±0.13
Org Low	1478	±96	502	±45	250	±71	2.2	±0.08	0.17	±0.01	28	±3.4	16.17	±0.48	105	±9	5.7	±0.09
Sites																		
Chuka	1887	±62	519	±38	271	±8	0.34	±0.05	0.202	±0.004	39	±2.7	19.7	±0.7	119.6	±11	5.74	±0.06
Thika	1487	±106	805	±44	285	±10	0.27	±0.03	0.158	±0.004	33	±2.4	17.1	±0.4	182.5	±14	5.88	±0.11
Seasons																		
SI	1772		728		292		32		2.23		0.17		34		4.2		219.69	
SII	1642		667		277		105		2.24		0.18		44		2.4		155.42	
SIII	1566		640		267		25		2.31		0.19		29		3.5		88.39	
Sources of variations																		
Farming systems	***		***		***		Ns		***		***		***		***		***	
Site	***		***		ns		***		Ns		ns		***		***		***	
Season	ns		Ns		ns		***		Ns		*		**		*		ns	
Correlation	***		***		ns		*		***		ns		***		ns		*	

	Micronutrients											
	Boron		Cu		Fe		S		Zn		Al	
Farming systems												
Conv High	0.66	±0.11	1.58	±0.16	99	±44	19.9	±2.9	9.04	±1.1	0.10	±0.02
Org High	1.15	±0.1	1.7	±0.2	79	±32	16.	±3.3	9.2	±0.9	0	±0.0

			7		1			9					1
Conv Low		0.58	±0.08	1.46	±0.14	86	±41	17.2	±2.3	6.6	±1.1	0.2	±0.05
Org Low		0.72	±0.15	1.4	±0.09	90	±41	14.3	±1.6	8	±1.4	0.1	±0.02
Sites													
	Chuka	0.68	±0.04	1.83	±0.14	87.1	±8.4	9.74	±0.5	11.2	±0.6	0	±0.01
	Thika	0.86	±0.13	1.3	±0.03	90	±9.8	22.6	±2	5.8	±0.5	0.1	±0.03
Seasons													
	SI	6		1.53		88		451		14.2		8.22	
	SII	-		-		-		-		-		-	
	SIII	-		-		-		-		17.4		-	
Sources of variations													
Farming systems		*		Ns		***		Ns		*		**	
Site		ns		Ns		ns		Ns		ns		**	
Seasons		ns		Ns		ns		Ns		ns		ns	
Correlation		ns		***		**		***		**		***	

Appendix VI: Crop phenology for the maize cultivars used in the long-term SysCom project at Thika and Chuka trial sites

		Crop phenology	
Weeks after emergence (WAE)	**Days since emergence**	**Baby corn**	**Dry maize**
1	7	Germinate	Germinate
2	14	2 to 3 leaf	2 to 3 leaf
3	21		
4	28	Vegetative	Vegetative
5	35	knee high	knee high
6	42	Knobbing	Knobbing
7	49		
8	56	Tasseling	Tasseling
9	63	Silking	100% tasseling
10	70	1st- 2nd harvest	Silking
11	77	3rd- 5th harvest	
12	84	6th-8th harvest	Knobbing
13	91	8th-9th harvest	Knob filling
14	98	10th-11th harvest	
15	105	12th harvest	
16	112	13th-15th harvest	Browning
17	119	16th-17th harvest	50% drying
18	126	18th harvest	
19	133		Drying
20	140	19th harvest	Final harvesting

Appendix VII: The prevailing weather factors at Chuka and Thika over the tria; periods 2014 I, 2014 II and 2015 I

		Chuka							Thika						
Year	Month	Max Temp (°C)	Max RH (%)	Min Temp (°C)	MinRH(%)	Average Temperature (°C)	Average RH (%)	Rainfall (mm)	Max Temp (°C)	Max RH (%)	Min Temp (°C)	MinRH (%)	Average Temperature (°C)	Average RH (%)	Rainfall (mm)
2014	January	26.2	94.3	13.2	53.3	19.7	73.8	231	28.3	95.1	13.8	38.2	21.0	66.6	104.8
2014	February	27.9	88.1	13.1	41.8	20.5	64.9	2	29.1	87.8	14.0	32.7	21.2	58.8	27.1
2014	March	28.6	90.2	15.5	35.7	22.0	62.9	39.5	29.5	88.4	16.0	33.6	21.5	62.2	100.4
2014	April	26.1	68.2	16.2	29.9	21.2	49.1	351.5	25.8	98.0	15.7	47.9	19.8	76.9	270.9
2014	May	25.8	83.1	15.6	41.6	20.7	62.3	14	27.1	69.3	15.1	31.8	19.9	50.4	7.4
2014	June	23.6	82.0	14.0	41.8	18.4	61.9	11.5	24.0	45.1	13.5	24.0	18.1	32.0	6.4
2014	July	22.2	69.8	14.0	35.2	18.1	52.5	46.5	22.5	92.0	13.3	17.3	42.6	40.9	28.3
2014	August	24.6	79.2	14.4	37.4	19.5	58.3	18	24.6	83.0	14.2	19.5	38.0	0.0	3.8
2014	September	27.2	89.0	14.8	33.4	21.0	61.2	19.5	27.9	62.2	13.7	24.5	20.1	39.5	15.6
2014	October	26.0	94.0	15.9	44.1	20.9	69.1	218.5	27.0	64.1	15.7	25.7	20.4	42.7	70.9
2014	November	26.2	87.2	16.4	48.4	20.9	70.0	237	26.5	69.5	15.7	20.6	25.7	46.8	158.5
2014	December	27.3	74.9	14.1	33.5	20.1	54.5	12.5	27.9	57.4	14.0	21.6	22.4	36.0	1.6
2015	January	27.4	59.9	14.1	25.9	20.3	40.5	126	27.7	43.9	13.4	23.6	20.4	29.9	49.3
2015	February	27.9	60.0	15.0	24.6	20.8	38.4	40	28.2	46.7	14.4	23.4	21.0	30.0	19
2015	March	29.8	67.9	17.1	29.6	22.8	46.0	158	29.7	48.8	15.4	23.5	22.3	31.0	51.5
2015	April	26.5	57.5	16.6	24.3	20.9	38.5	146	27.1	62.2	16.5	23.8	21.1	38.5	173.7
2015	May	26.1	55.6	16.0	24.3	20.4	37.4	129	25.8	51.3	15.9	23.9	20.0	34.6	94.7
2015	June	27.6	45.9	15.1	23.4	20.3	31.3	2.5	25.9	45.6	14.9	24.7	20.0	31.9	10.1
2015	July	26.1	70.4	14.8	33.1	19.6	51.4	0	25.6	40.5	13.0	23.4	18.8	28.5	1.1
2015	August	24.5	87.4	14.4	41.1	18.6	65.5	1.5	24.8	40.0	13.4	23.4	18.3	28.5	1.7
2015	September	29.3	85.2	15.4	28.8	21.6	54.9	2.5	27.5	36.3	14.2	23.4	20.3	26.6	0
2015	October	26.8	91.4	16.0	39.7	20.5	67.0	335	26.3	46.8	15.4	23.5	20.1	31.7	133.7
2015	November	25.7	83.0	16.1	39.1	20.4	60.1	295.5	26.2	44.1	16.0	23.4	20.3	30.5	111.4

2015	**December**	**26.0**	**55.2**	**15.9**	**25.8**	**20.3**	**38.7**	**37.5**	**25.8**	**49.1**	**15.5**	**23.6**	**19.9**	**33.0**	**94.2**