INTEGRATED SOIL NUTRIENT MANAGEMENT TECHNOLOGIES FOR IMPROVED MAIZE (*Zea Mays* L.) PRODUCTIVITY IN MURANG'A AND THARAKA-NITHI COUNTIES, 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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To my loving parents Mr. and Mrs. Otieno and all my siblings.

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ACRONYMS AND ABBREVIATIONS

ANOVA	Analysis of Variance
CEC	Cation Exchange Capacity
CT	Conventional Tillage
ISNMTs	Integrated Soil Nutrients Management Technologies
ISFM	Integrated Soil Fertility Management
LR	Long Rains
MT	Minimum Tillage
OC	Organic Carbon
OI	Organic Inputs
SFM	Soil Fertility Management
SOC	Soil Organic Carbon
SOM	Soil Organic Matter
SR	Short Rains
SSA	Sub-Saharan Africa

ABSTRACT

Continuous land cultivation without adequate soil nutrients replenishment causes soil fertility decline leading to reduced crop productivity. Significant research on external fertility inputs application rates and type have been carried out under researcher designed and managed conditions in Kenya. But little research on the same has been carried out to evaluate their performances under on-farm smallholder farmers' conditions. Hence, the study evaluated the decomposition rates (goat manure and *Tithonia diversifolia*) and performance of selected integrated soil nutrients management technologies on soil nutrients amounts and maize productivity under two tillage methods. On-farm trials were laid out in randomized incomplete block design. There were two control treatments; conventional tillage-control (CON-C) and minimum tillage-control (MIN-C). Each tillage method was combined with different soil fertility inputs. Soil fertility inputs included mineral fertilizer, rock phosphate, crop residue, legume intercrop, goat manure and *Tithonia diversifolia*. Compared to CON-C, in Meru South, N and K significantly increased under minimum tillage+crop residue+*Tithonia diversifolia*+goat manure and minimum tillage+crop residue+*Tithonia diversifolia*+rock phosphate by 100 and 52%, respectively. In Gatanga, nitrogen, phosphorus and potasium significantly increased under minimum tillage+mineral fertilizer, conventional tillage+crop residue+mineral fertilizer+goat manure and minimum tillage+crop residue+goat manure+legume intercrop by 33, 78 and 34%, respectively. The highest decomposition rate constants were 0.024 and 0.015 d^{-1}, and 0.020 and 0.014 d^{-1} for *Tithonia diversifolia* and goat manure in Meru South and Gatanga, respectively. Relative to CON-C, minimum tillage+crop residue+*Tithonia diversifolia*+rock significantly increased maize grain yield by 89 and 91% in Meru South and Gatanga during SR2016 and LR2016, respectively. The selected soil nutrient management technologies were preferred based on the ability to improve soil fertility, crop yield, ease of implementation, availability of inputs and labour and farmer's age. The study concludes that selected soil nutrients technologies improve soil fertility and maize grain and stover yields thus are likely to be taken up by farmers. *Tithonia diversifolia* and goat manure can be used to synchronize crop-nutrient release.

Chapter 1

1.0 INTRODUCTION

1.1 Background information

Soil degradation is a primary challenge affecting the sustainability of both crop and livestock productivity systems globally (Zingore *et al.*, 2015). In Kenya, it is worse because farmers practice crop-livestock farming systems on already degraded lands (Castellanos-Navarrete *et al.*, 2015). Maintaining soil productivity is one of the main challenges that have led to reduced crop productivity per unit area in the Central Highlands of Kenya (Jayne and Muyanga, 2012). The declining soil fertility positively correlates to deteriorating soil organic matter (SOM), which vital an important measure of soil quality (Dikgwatlhe *et al.*, 2014). Soil organic matter is one of the predominant factors in soil degradation affected by continuous cultivation and low organic soil fertility input application (Lal, 2007). Improving soil organic matter can depend on the application of external soil fertility inputs.

Soil fertility inputs, especially of organic origin, can be vital in improving soil fertility and SOM (Vanlauwe, and Giller, 2006). The inputs increase the availability of mineralisable nitrogen (N) (Tu, 2006) and improve bulk density (Meena, 2015). This leads to sustainable crop yield production (Blanchet *et al.*, 2016). Organic inputs release nutrients slowly thereby reducing chances of leaching (Chen, 2006) thus the nutrients are available for plant uptake over prolonged time. *Goat* manure can increase plant nutrients, microbial quality and improve soil physical properties (Yang *et al.*, 2016; Faissal *et al.*, 2017; Ström *et al.*, 2018). Legume intercrop and *Tithonia diversifolia* can improve soil fertility parameters (Güereña *et al.*, 2016; Adekiya, 2017). Utilising crop residues as mulch modifies soil micro-climate hence increase microbial community and improve nutrients availability and uptake by plants (Hellin *et al.*, 2013). Phosphate rock is a vital soil input in crop production especially under acidic soils (Babana *et al.*, 2016; Krauss *et al.*, 2017) because it slowly releases P. Thus, a combination of such external soil fertility inputs could be appropriate in the quest of not only to reverse land degradation but also as an initiative for addressing declining agricultural productivity in the Central Highlands of Kenya.

Mineral fertilizer is another important soil fertility input. However, the use of mineral fertilizers in Central Highlands of Kenya is still insufficient (Mugwe *et al.*, 2009), further worsening soil nutrient status (Place *et al.*, 2003). High costs of purchase and transportation, poor quality of and limited access to mineral fertilizers are some of the reasons that could explain the inadequate use. Organic inputs have the potential of filling the nutrient deficit created by inadequate use of mineral fertilizers, either solely or in combination with mineral fertilizers (Ngetich *et al.*, 2012). Nonetheless, the efficiency of applied external soil fertility inputs could be affected by tillage method.

Tillage system may lead to accumulation or loss of SOM (Ji *et al.*, 2013) depending on which tillage method is used. Whereas, minimum tillage can cause an annual increase in organic carbon (OC) (Powlson *et al.*, 2012), conventional tillage can control weeds (Brandsæter *et al.*, 2017) improve N, P and K accumulation, promote root development, and increase soil water content and water use efficiency (Tao *et al.*, 2015) thus improve crop yield (Ranatunga *et al.*, 2008). However, CT can cause surface runoff as well as sediment loss (Endale *et al.*, 2017). Although organic input-based technologies have the potential of filling the nutrient deficit created by inadequate use of mineral fertilizers, either solely or in combination with mineral fertilizers (Ngetich, 2012), their uptake is still low. Hence, there is a need to integrate organic resources such as crop residues (maize stover), *Tithonia diversifolia* and goat manure, with or without mineral fertilizers under minimum and conventional tillage methods in order to evaluate their effects on maize productivity under on-farm conditions.

1.2 Statement of the problem

Declining soil fertility and low adoption of developed organic resource management technologies are the primary causes of the declining crop and the widening yield gaps in the Central Highlands of Kenya. The yield gap can be attributed to limited available nutrients replenishing sources/resources leading to poor soil fertility status. Though conditions at farm levels vary considerably, less is still known on how maize productivity responds to different soil fertility management measures. This has been occasioned by the fact that most soil fertility related research have mostly been carried out and tested under on-station, researcher managed conditions. Moreover, less effort has been directed towards characterizing qualities of organic inputs at smallholder farm levels. This therefore calls for initiatives to determine crop responses to the selected integrated soil nutrients management technologies and characterization of organic inputs qualities under on-farm conditions.

1.3 Justification

Scarcity and the competing uses of available resources are among the challenges faced by smallholder farmers at farm levels thereby affecting important farming decisions. The interplay between resource scarcity and competing uses not only affects the amount, but also the type of inputs used. Farmers should therefore be informed on sustainable ways of integrating the resources they have to improve their food production without adversely affecting the other competing uses. To achieve this, farmers' fields are important learning platforms that can be used for comparative research for development and ease of technology acceptance and up-take.

1.4 Objectives

1.4.1 General objective

The general objective of the study was to evaluate the effects of the selected integrated soil nutrients management technologies on maize productivity under on-farm conditions in Murang’a and Tharaka-Nithi Counties.

1.4.2 Specific objectives

1. To determine the effects of the selected integrated soil nutrients management technologies on selected soil physical and chemical properties in farmer managed trials.
2. To determine quality and decomposition rates of the selected organic inputs under on-farm conditions.
3. To determine the effect of the selected integrated soil nutrients management technologies on maize grain and above-ground biomass yield under farmer-managed trials.
4. To assess the likelihood of farmers' up-take of the selected integrated soil nutrients management technologies.

1.5 Hypotheses

1. The selected integrated soil nutrients management technologies have no significant effect on soil physical and chemical properties under on-farm conditions.
2. Quality and decomposition rates of the selected organic inputs do not vary significantly under on-farm conditions.
3. The selected integrated soil nutrients management technologies do not have significant effects on maize yields under farmer-managed trials.
4. There is no significant likelihood that the farmers will take up the selected integrated soil nutrients management technologies.

1.6 Conceptual framework

The declining soil fertility problem in the study area is caused by inadequate use of mineral fertilizer, continuous land tilling, and limited use of organic inputs (Fig. 1.1). The problem leads to low per capita maize production which can be solved by implementation of integrated soil nutrients management technologies. The technologies involve the use of quality organic inputs solely or in combination with mineral fertilizers with a suitable tillage method. This approach is the foreseeable intervention with the potential of improving soil fertility leading to increase in per capita maize production in the study area.

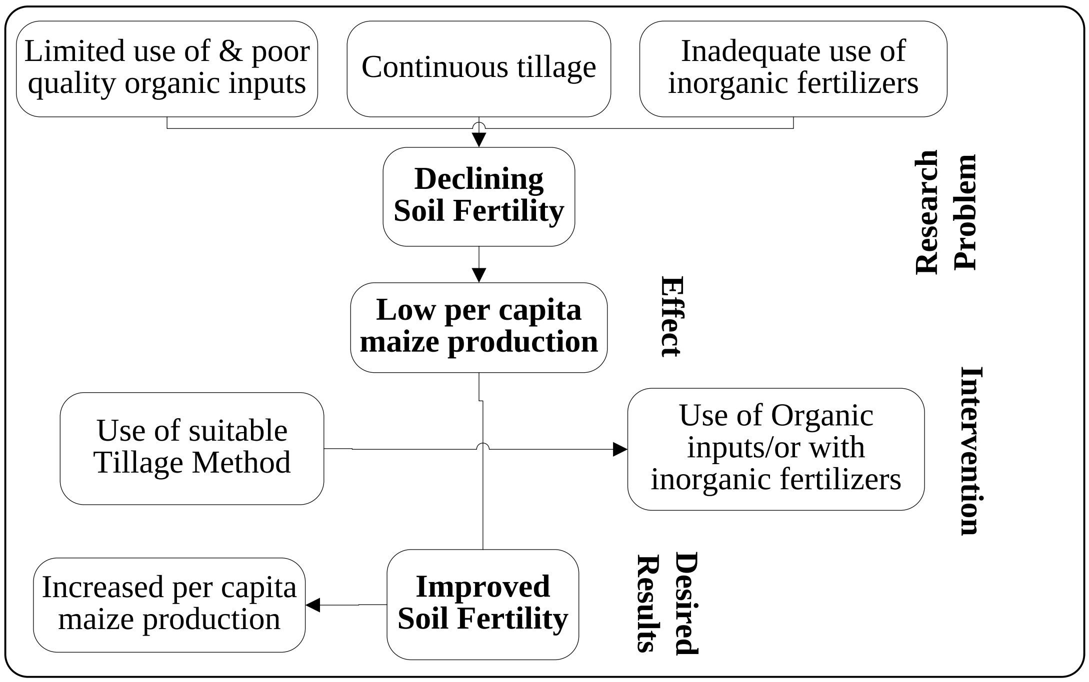

Figure 1:1.1: Conceptual framework

To assess the likelihood of farmers' up-take of the selected integrated soil nutrients management technologies, the study adopted the concept of innovation-decision stages as explained by Rogers (2003) (Fig. 1.2). Technology adoption follows five steps; acquisition of knowledge, persuasion, decision formation, implementation and confirmation (Sahin *et al.*, 2006). This study, however, covered up to the decision formation stage because at the end of the study, the target farmers had been informed and taught on implementation of the selected technologies.

By training the farmers, they learn and gather information on selected integrated soil nutrient management technologies. After learning, an attitude was formed as influenced by the certainty/uncertainty levels and peers' subjective assessment of the technologies. Thereafter, at the end of the experiment, the target farmers decided to take-up the selected technologies or not. Rogers (2003) suggested that, partial trial basis hastens adoption since individuals prefer to try a new idea in their own situation before deciding to adopt or reject it. According to the concept, there are two types of rejections, that is, active and passive. In active rejection, a person first tries a technology, contemplates to adopt it but later rejects it while in passive rejection a person does not even consider the possibility of adopting the technology.

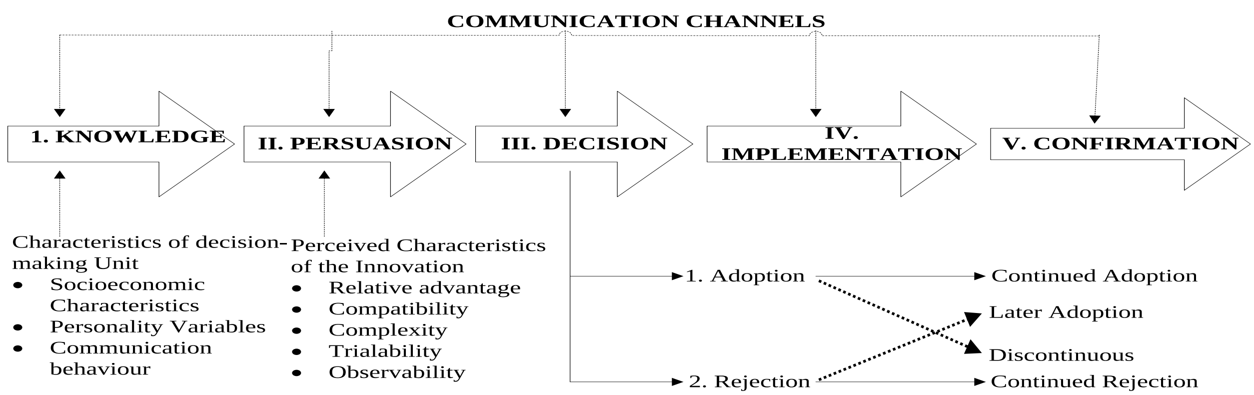

Figure 1:2: Innovation-decision theory adapted from Sahin *et al* (2006)

Chapter 2

2.0 LITERATURE REVIEW

2.1 Overview of the study

Soil fertility in the Central Highlands of Kenya is declining. The decline in soil fertility has caused reduction in crop productivity among smallholder farmers in the study site. The problem of the deteriorating soil fertility is mainly caused by nutrient mining where there is no adequate replenishment of the harvested nutrients. The farmers have also over time persistently dwelt in land tilling which might be among the reasons of the reduction in soil fertility in the study areas. To improve soil fertility, past studies have proposed the use different soil fertility inputs such as organic inputs. This study looked into how various inputs affected soil fertility and maize productivity under on-farm conditions.

2.2 Soil fertility improvement

Soil fertility status in Sub-Saharan African and Central Highlands of Kenya in particular, is declining and will not sustain crop production demand of the future generations (Godfray and Garnett, 2014). Therefore, there is increasing need for soil fertility status to be replenished to meet the crop production demand. This can be achieved through application of external soil fertility inputs such as mineral fertilizer and organic resources.

Sole application of mineral fertilizers increase crop yield but in the short-term (Zhang, 2009) and has been thought to have negative environmental impacts such as nutrient loss and acidification (Cai *et al*, 2015). Other studies have shown that various strategies such as manure could replace mineral fertilizers, increase SOC and consequently, maize yield (Li *et al*, 2017). Alternatively, crop productivity can be increased through combining organic and mineral fertilizers. However, the suitability of this approach varies according to soil type, soil nutrient reserves and climate (Diacono *et al*, 2010; Ding *et al*, 2015). It is important that the use of combinations of mineral and organic inputs in the Central Highlands of Kenya is assessed. The region characterised with highly weathered *Humic nitisols* which are generally acidic.

One of the challenges of highly weathered soils is nutrients availability and retention. Soil available P is specifically a problem in acidic soils due to its fixation and can seriously limit crop production. Nonetheless, this problem can be solved by applying mineral fertilizers (Magnone *et al.*, 2017). Additionally, other soil nutrients (such as N, P and K) can be made available through organic resources such as goat manure (Yang *et al.*, 2011), rock phosphate (Husnain *et al.*, 2014), *Tithonia diversifolia* (Rasche *et al.*, 2014) and legume intercrop (Mucheru-Muna *et al.*, 2010; Nabel *et al.*, 2016; Smith *et al.*, 2016). A study conducted in *Humic nitisols* of the Central highlands of Kenya using various organic and mineral resources found that cattle manure increased soil pH, calcium (Ca), Mg and K while *Tithonia diversifolia* lowered pH, carbon (C) and N, but improved Ca, K and Mg (Mugwe *et al.*, 2009). It is therefore important to understand the effect of various soil fertility inputs on soil fertility status and crop productivity.

2.2.1 The role of mineral fertilizers on crop productivity

Persistent declining soil fertility remains the primary biophysical threat to per capita food security among Central Highlands of Kenya smallholder farmers. For instance, low levels of total nitrogen, organic carbon, phosphorus and pH at less than 0.2%, 2.0%, 10 ppm and 4.8-5.4, respectively have been cited to lower maize yield from 6 to 10 t ha^{-1} to approximately 0.5-1.5 t ha^{-1} (Mugwe *et al.*, 2007). The decline in soil fertility is caused mainly by nutrient mining and unbalanced application of nutrients. Mineral fertilizers can be used, solely or combined with organic inputs, to replenish the mined nutrients. A study conducted in Nigeria on effects of mineral NPK fertilizers on soil properties reported positive results on N, P, potassium (K) and magnesium (Mg) but no change was observed in organic matter and soil bulk density (Adekiya *et al.*, 2017). In Rwanda, Rurangwa *et al.* (2017) found that maize yield increased from 0.8 to 1.9 t ha^{-1} following the application of P fertilizer and manure on legumes of the previous season.

Additionally, the use of mineral NPK fertilizer improved both growth parameters and cassava yield in Congo (Munyahali *et al.*, 2017). Similarly, in a maize-cassava-intercrop, maize growth and yield was found to have improved when mineral and organic fertilizers were integrated (Ayoola, 2007). In another study, fertilization with K fertilizer led to uptake of various nutrients in different parts of potatoes (Neshev and Manolov, 2015). Moreover, a review of the historical nutrient depletions revealed that soil mineral contents are stable in areas where crop production is based on intensive use of different mineral fertilizers (Marles, 2017). These results, in part, show the importance of mineral fertilizers in improving crop and food production in nutrient-depleted soils.

However, the use of mineral fertilizers in Sub-Saharan Africa is low as compared to the rest of the world. The application rate is at 10 kg ha^{-1} relative to 87 kg ha^{-1} in the developed nations (Ngetich *et al.*, 2012) thus sole reliance on mineral fertilizers in improving soil fertility is not currently feasible in the region. Moreover, the use of mineral fertilizers among smallholder farmers have been limited the divided opinions on their impact on environmental safety and sustainability. One of the concerns is that the used fertilizers end up polluting water resources (Smith and Siciliano, 2015) posing health hazards because some of the fertilizers contain heavy metals though this could be resolved using fungi communities present in phosphate fertilizers (Abd *et al.*, 2015). Other researchers (e.g. Mohd *et al.*, 2015) have suggested that synthetic fertilizers lead to emission of greenhouse gases such as nitrous oxide (Akhir *et al.*, 2015).

2.2.2 Organic inputs for soil fertility amelioration

Organic inputs such as legumes, manure and crop residues are important soil amendments (Vanlauwe and Giller, 2006). The amendments increase soil organic carbon (SOC) and improve soil aggregate stability (Kuzyakov, 2010) and improve yields for the succeeding cropping season. Most importantly, organic inputs release nutrients (nitrogen and phosphorus) slowly thereby reducing chances of leaching (Chen, 2006).

Crop residues are one of domestically available resources in agricultural homestead that potentially, can improve soil fertility. Results by Abdullah (2014) showed that 4 t ha^{-1} of wheat residue increased SOM by 18%. Additionally, Song *et al.* (2015) studied the effect of different fertilization practices on soil properties and ascertained that soil nutrient availability and SOC increased significantly on NPK plus maize straw. There is need to study effect of residues in combination with other inputs to better understand nutrient dynamics and soil physical conditions as affected by the inputs combination in on-farm conditions.

Goat manure is an important waste product which is a primary component of integrated soil fertility management. For instance, cow dung significantly improved N, P and effective K in Beijing (Yang *et al.*, 2011). In Nigeria, incorporation of poultry manure into soil led to increased SOC, N, P, Mg and calcium (Ca) (Adekiya and Agbede, 2016). However, there was a slight change on total porosity and soil bulk density. Subsequently, combination of dairy manure with NPK annually increased P by 77 Kg ha^{-1} in China (Yang *et al.*, 2014). In the Kenya Central Highlands, application of manure reduced exchangeable acidity, raised pH and improved Mg, Ca and K (Serafim *et al.*, 2016). However, there is still limited understanding of effect of combining goat manure with non-recalcitrant carbon (C) sources on maize productivity.

Tithonia diversifolia is a nutrient-rich shrub (Sanchez *et al.*, 1997; Palm *et al.*, 2001) and has been used as biomass transfer technique (Ngetich *et al.*, 2010). The shrub is common as live fence in most homesteads in Central Highlands of Kenya but rarely used as soil fertility input. A study in Western Kenya showed that *Tithonia diversifolia* increased maize yield more than mineral fertilizers (Jama *et al.*, 2000). In South western Nigeria, application of *Tithonia diversifolia* in degraded soils improved early stages of maize growth and increased grain yield by 88 to 94% (Ademiluyi and Omotoso, 2007).

Intercropping with legumes provides quick ground cover, fixes N and increases chances of plant roots to explore nutrients at varying depths thereby promoting sustainable agro-ecosystem (Ayoola, 2015). Maize intercropped with either groundnuts (*Arachis hypogaea*), soybeans (*Glycine max*) or pigeonpea (*Cajanus cajan*) improved maize grain yield compared to sole maize system in on-farm trials conducted in Malawi (Smith *et al.*, 2016). Additionally, it was found that N application reduced by 23-31 N kg ha^{-1} on subsequent cropping season succeeding legume intercrop while cereal yield increased roughly by 0.5-1.6 Mg ha^{-1} in Europe (Preissel *et al.*, 2015). In Mukuuni (Meru South) and Machang'a (Mbeere), Kenya, beans (*Phaseolus vulgaris*) and groundnut intercrops led to negative N balances while cowpea intercrop resulted in neutral N balances (Mucheru-Muna *et al.*, 2010). More benefits of legumes like alfalfa (*Medicago sativa*) intercropping, such as increased crop biomass production, have been cited (Nabel *et al.*, 2016). However, effect of *Dolichos lablab* intercrop on soil fertility parameters and maize productivity has been scarcely researched in the study area.

2.3 Decomposition of organic inputs

Sustaining agricultural intensification and soil fertility require accumulation of SOC which relates to soil organic matter (SOM). Accumulation of SOM is affected by soil properties (e.g. moisture) (Blonska and Lasota, 2017) and plant litter decomposition rates as influenced by temperature (Carey *et al.*, 2017). With proper agronomic management practices, plant litter can be used to synchronize nutrient release to crop requirements at various growth stages. Decomposition rate- which to a greater degree depends on litter quality and chemistry (Singh *et al.*, 2017), and agricultural management practices (Naijia *et al.*, 2017), affects the frequency of SOM accumulation, energy and nutrient recycling. Litter such as cattle manure has been found to exhibit slower decomposition rates and proposed as a carbon (iv) oxide (CO_2) emission control strategy in climate-smart farming system (Hossain *et al.*, 2017). It is therefore important to understand factors that affect plant litter decomposition rates.

2.3.1 Determinants of decomposition rates

Decomposition rates of different litters vary in space and time as dictated by interactions between climatic factors and plant molecular types and quality (Bradford *et al.*, 2016). In the localized study of plant litter decomposition where climate is comparatively uniform, studies have shown that quality of the litter drives decomposition rates rather than climatic factors (Rovira and Vallejo, 2007). Molecular quality of decomposing litter depends on the available substrates to soil microbial community. Plant litters have differing decomposition rates due to varied bimolecular components (Berg and McClaugherty, 2013) hence are susceptible to microbial attack in different proportions and time. In the past studies, researchers (e.g. Cornwell *et al.*, 2008) have attempted to find litter quality indicators that provide accurate determinant to decomposition rates.

Lignin was initially thought to be the most predictive biomolecule that determined decay rates by past studies (for instance Coq *et al.*, 2010). Moreover, C:N and lignin: N ratios have received considerable amount of support in regard to decomposition rate predictors. These two ratios have for long been considered to be the quality traits of OM that control mass loss rates (Shibu *et al.*, 2006). However, recent studies have warned against the use of C: N and lignin: N ratios in predicting decay rates. For example, C:N ratio should not be used throughout in determining decomposition rates (McClaugherty, 2013) because regardless of its original value, it continues to decrease because C and N are lost through microbial respiration and immobilization, respectively (Bonanomi *et al.*, 2010).

A study conducted almost a decade ago found strong positive association between non-lignin C (though in low concentrations) and decay rates in tropical ecosystems (Hättenschwiler *et al.*, 2011). In almost similar study conducted a few years later, Bonanomi *et al* (2013) studied decomposition rates of 64 different types of litters and found a weak correlation between C:N ratio and decomposition rates. Despite the massive litter decomposition studies, a few have attempted to relate other labile components (e.g. macro and micro-nutrients) to decay rates. In this regard, the potential of goat manure and *T. diversifolia* to release labile nutrients through decomposition have not been studied in the Central Highlands of Kenya.

Addition of organic materials triggers priming effect that facilitates SOM decomposition (Andersen, 2016). However, substrate quality is important in determining available energy for microbes to readily decompose SOM. Recalcitrant materials such as lignin and polyphenol contain less energy than labile ones like cellulose and hemi-cellulose thus decompose more slowly (Sebastien *et al.*, 2003). The slow decomposition rate could be due to two effects of low molecular N. First, it reacts with remnant lignin to form complex recalcitrant compound; second, it oppresses synthesis of lignin-decomposing enzymes. Nitrogen deposition effect on SOM mineralization vary depending on decomposition phases which are categorized as early, late and final phases (Berg and Matzner, 2016).

It has also been observed that P fertilization affects decomposition rate. For example, P fertilization causes P-immobilization, lowers C:P ratio and accelerates decomposition of dissolved organic matter (Cleveland and Townsend, 2006). Labile plant compositions are the primary microbial products, important for SOM stabilization through improved aggregation and chemical bonding with mineral soil matrix (Cotrufo, 2016). However, the effect of combining different fresh organic matter (FOM) in varied tillage systems on SOM mineralization is scarcely discussed in the available literature.

2.4 Tillage methods

Tillage is an activity that forms the basis of initial farm operations amongst smallholder farmers. It is a means of soil surface management operation. Tillage methods have become an area of research interest in the past decades albeit contradicting results. Soil organic carbon (SOC) is a measure of soil quality that would improve crop productivity but research has shown that tillage is one of the pathways in which it is lost from agricultural lands. A study conducted on an on-farm experiment revealed that agricultural fields can gain organic carbon from different sources such as rainfall and irrigation but can lose about 1072 kg ha^{-1} $year^{-1}$ through runoff and erosion (Nachimuthu and Hulugalle, 2016) as a result of tillage. Sime *et al.* (2015) found economic and agronomic responses to tillage in a maize-based system in Ethiopia.

Tillage also affects SOM which supports many soil quality parameters (Palm *et al.*, 2007) like bulk density, moisture content, penetration resistance and root length density (Ji *et al.*, 2013). It is thought that tillage method impacts on soil physical, chemical and biological properties as well as crop yields as detailed on the review of the benefits of conversational and conservational tillage methods by Busari *et al.* (2015). A shift from conventional to conservation tillage method resulted into better aggregate stability, carbon stock, reduced pH and increased particulate organic matter (Mrabet *et al.*, 2000). Also, reduced plough can lead to an annual increase in organic carbon (OC) (Powlson *et al.*, 2012).

Moreover, reduction in tillage intensity led to higher mean aggregate sizes (Lvaro-Fuentes *et al.*, 2008) while macro and micro-aggregates increased and decreased by approximately 50.13% and 10.1% respectively in China (Choudhury *et al.*, 2014). However, Du *et al.* (2015) reported that minimum tillage increased micro-aggregate by 31% while causing formation of new ones by 23%. A study done in England showed that conservation tillage did not lead to accumulation of SOC but rather affected its distribution in soil profile (Baker *et al.*, 2007). Another study conducted by Pinheiro *et al.* (2015) revealed even distribution of SOC in soil fractions >55%. In contrast to conventional tillage, OC is accumulated in soil mineral fraction in minimum tillage. To meet food demands of the estimated future populations, there is need for succinct research on tillage methods in this decade and beyond.

2.4.1 Minimum tillage

Minimum tillage is an important component of conservation agriculture (CA) that aims at limiting soil disturbances and retaining crop residues to improve soil fertility and crop production. Shifting to minimum tillage comes at a cost, in terms of yield reduction in the initial years of implementation. A study conducted to quantify trade-off between three aspects, probable yield declines, reduced farming costs and improved crop fortification expenses found that though reduced tillage led to environmental and financial benefits, there was a crop reduction ranging from 0-14.2 per cent (Townsend *et al.*, 2016). Similar findings were obtained under CA experimented on-farm in Nepal where farmers did not receive increased maize yield but rather benefited from higher financial gains (Paudel *et al.*, 2014).

Tillage also has effect on SOC. Soil organic carbon (SOC) sequestration is considered a crucial agricultural strategy to reduce emission of greenhouses gases. Ghimire *et al.* (2017) did a review of the existing literature on impact of nutrient management activities, tillage and crop residue on SOC and found a number of studies supporting that application of N from goat manure, reduced tillage, and crop residues increased accumulation of SOC in rice-based systems in South Asian countries. The increased SOC accumulation could be due to soil conservation associated with the minimum tillage that was found to increase maize production by 96%-98% and reduced energy consumption (Rusu, 2014). Though, SOC is higher in uncultivated/reduced tilled lands, it varies temporarily, spatially and among different soil types thus should be managed in accordance to its density and the capacity of a particular soil to sequester carbon (Cao *et al.*, 2016).

The tillage method also improves other soil fertility properties such as physical, chemical and biological parameters (Chetan *et al.*, 2016). Soil water is one of the most important crop requirements which become even critical in dry regions yet has been found to be affected by tillage method practiced. Kuzucu and Dökmen (2015) found that reduced tillage and mulching had positive impact on soil water content (SWC). Soil water conservation affected soil properties such as bulk density, SOC and total N in Ethopia (Hishe *et al.*, 2017). The impact of reduced tillage on soil biological properties (microbial community diversity) has gained importance in soil fertility conservation studies (Bissett *et al*, 2013; Silvia *et al*, 2014; Zhang *et al.*, 2015; Ashworth *et al.*, 2017). However, the results of past studies in regard to the potential of CT to improve maize yield have been contradictory.

Topsoil tillage has been suggested to reduce crop yields in some quarters. Nitrogen fertilization under reduced tillage leads to a decline in crop yields (Lundy *et al.*, 2015). A global meta-analysis study suggested that topsoil tillage averagely reduces yields by 5.1 per cent over 50 different crops but performs better, matching conventional tillage, in rain-fed situations (Pittelkow *et al.*, 2015). With the increasing suggestions on the suitability of minimum tillage, it would be of importance to assess the impact of this tillage method on maize productivity in on-farm trials in Central Highlands of Kenya that has a rapid population growth rate.

2.4.2 Conventional tillage

Conventional tillage (CT) is a common practice among smallholder farmers and characterized with continuous deep/subsoil ploughing a depth of 20-30 cm. This tillage method leads to soil disturbance and affects various soil fertility properties and crop productivity. Probably farmers rely on this type of tillage to control perennial weeds as was found in Norway (Brandsæter *et al.*, 2017) which would otherwise be expensive using chemical control measures. Weed competitions reduce crop yields by limiting nutrient uptake as was discovered by (Seyyedi *et al.*, 2016). A study conducted in Iran showed that effective weed management increased maize yield (Yeganehpoor *et al.*, 2015).

A long-term experiment conducted in the period of 2004-2011 in USA reported increased grain yield under CT as a result of improved total soil carbon (C) and N (Sainju *et al.*, 2017). In another study conducted in Northern Huang–Huai–Hai, maize yield was improved due to better water use efficiency when CT was combined with mulch. In another study, water consumption decreased by 6.3-7.8 per cent, maize production, soil water content and water use efficiency increased by 644.5-673.9 kg/ha, 2.9-3.0 per cent, and 12.7-15.2 per cent, respectively, under deep tillage (Tao *et al.*, 2015).

Subsoil tillage also affects various soil chemical processes. Microbial competition for both N and C is as massive in deep tillage as it is in reduced tillage (Jones *et al.*, 2018). In a four-year experiment, it was found that CT improved N, P and K accumulation, root development and maize yield (Cai *et al.*, 2014). In a 7-year study conducted to assess effect of two types of tillage (strip and conventional) in USA, it was found that CT experienced surface runoff as well as sediment loss thus recorded significantly greater total organic C (TOC) and N (TON) loads relative to strip tillage that had significant higher concentrations of total organic C and N and their enrichment ratios (Endale *et al.*, 2017). Other studies (e.g. Strickland *et al.*, 2012) also found similar results in which TOC and TON enrichment ratios were higher in conservation tillage than they were in CT. Li *et al.* (2016) noted that factors such as type of soil, slope and intensity of rainfall have no effect on TOC under deep tillage.

Tillage also affects soil bulk density. Soil bulk density is affected by anthropogenic activities and can have impact on nutrient budget, especially soil C. A study conducted in Canada found exponential relationship between SOC and bulk density in both organic and mineral soils hence recommended prediction of bulk density using SOC. This approach could be useful in cases where determination of bulk density is expensive and cumbersome (Hossain *et al.*, 2015). Tillage method combined with different cropping systems affect bulk density at a depth of 0.15 cm (Hossain *et al.*, 2015). Though soil bulk density affects other soil properties and crop yields, there is a need for research to recommend to small-scale farmers tillage method that reduces energy inputs (Behera and

Sharma, 2011), and improves soil fertility such as C accumulation and biological functioning (Bhan and Behera, 2014) that can support stable crop production.

2.5 Effect of organic inputs on maize yield

The potential of organic resources in complementing or substituting chemical fertilizers is a potential solution to maize productivity in the study area. For instance, application of integrated inputs NPK plus corn straw and NPK plus farmyard manure increased annual maize yield by 0.184 and 0.137 t ha^{-1} respectively (Song *et al.*, 2015). Moreover, results of an experiment carried out in Nigeria by Ayoola and Makinde (2015) showed that maize had the best performance in terms of growth and yield under the complementary treatment of mineral and organic fertilizer. Additionally, an on-farm experiment carried out in Central Highlands of Kenya showed that maize responded significantly to application of cattle manure alone and cattle manure combined with 30 kg N ha^{-1} mineral fertilizer (Mugwe *et al.*, 2007). Nonetheless, the experiments were not compared under different tillage methods. Experiment undertaken in Ethiopia showed contrasting results. Maize yield increased by over 13% in conventional tillage relative to minimum tillage and by over 40% compared to zero tillage when treated with various organic inputs (Sime *et al.*, 2015). There is a need for a study that determines effects of various integrated technologies on maize yield and to assess whether the integration has additive, synergic or antagonism effect on maize yield.

2.6 Adoption of soil conservation technologies

Adoption of various technologies by farmers is not systemic or systematic but is influenced by varied factors. Farmers tend to adopt certain technologies based on perceived benefits. Majority (70%) of farmers in Tanzania adopted the use of conservation tillage, organic fertilizers and integrated farming based on improved soil fertility, crop yields and increased food adequacy as the perceived benefits (Shrestha and Ligonja, 2015). On-farm characteristics such as land ownership, farmer’s past participation, and training are among the reasons farmers participated in the adoption of soil and water management strategies in United States of America (Adusumilli and Wang, 2017).

Smallholder farmers in Kenya lack access to information and market to warrant technology adoption but are encouraged by their own additional income (Mogaka *et al.*, 2014). A study assessing decision to adopt fertilizer use in Burkina Faso found positive correlation between intra-household characteristics (e.g. gender, household head, age, access to extension services, membership to farmer groups and literacy) and adoption of fertilizer use (Haider *et al.*, 2017). Despite the various adoption studies small-scale farmers still experience slow adoption rates. In the Central Highlands of Kenya, the past adoption studies have not involved the farmers in key decision making processes before recommending various technologies to be taken up.

2.6.1 Likelihood of selected integrated soil nutrients management technologies up-take

A study done in the Central Highlands of Kenya showed that farmers cited declining soil fertility as a problem (Mairura *et al.*, 2008) but they are slow in taking up integrated soil fertility measures (Moser and Barrett, 2003; Mugwe *et al.*, 2012; Ngetich *et al.*, 2012). Land size could be one of significant factors explaining the slow adoption. Smallholder farmers find unattractive techniques that temporarily lead to yield decline and tie up land (Amsalu and Graaff (2006). Large land owners have the chance to put portions of their land on trials thereby making them risk-takers as compared to small land owners who are risk averse. Kessler *et al.* (2008) studied socioeconomic factors that influence up-take of soil and water conservation measures in five different countries and land size was one significant factor that affected the up-take of such measures. Knowler and Bradshaw (2007) also revealed the importance of land size on up-take or non-adoption of conservation agriculture as small land owners are reluctant to try the technique.

Small-scale farmers are attracted to techniques that yield short-term profitability and have least risks. Analysis of factors affecting up-take of stone terraces on soil conservation carried out by Amsalu and Graaff (2006) showed that farmers' perceived profitability of a technology affects their decision to adopt and continue using the technique or abandon it. According to the authors, farmers always have information that affect their decision and they tend to adopt technologies that will offset labour intensive practices while female farmers are unlikely to practice alley agroforestry than male farmers (Adesina *et al.* (2008). Unsuitability of a technology to farmers' needs and non-genuine participation of farmers in the early stages of a technique also affect up-take (Bewket, 2007). Kessler *et al* (2008) noted that farmers participating in implementing a given technology are likely to adopt it.

Moreover, agent of change such as researchers and extension officers may influence adoption (Hossain and Crouch, 1992; Moser and Barrett, 2003). Slow adoption trend could be attributed to lack of contact between the target farmers and the agent of change, and/or limited involvement of farmers in technology development. Up-take rate tends to be higher in areas where farmers are in close association with extension services (Adesina *et al*, 2008). Such contacts are necessary where disadoption rates are considerably high. This study therefore intended to assess whether farmer participation in research increase the likelihood of technology uptake. Additionally, it assessed technology-traits and farmer-traits that improved chances of taking up the tested technologies.

2.6.2 Adoption theories

Humans are dynamic creatures but whose actions could be explained by a number of theories. According to self-efficacy theory by Bandura, (1995), people desire to have control over what affects their lives and the ability to influence an outcome makes them predicable and promote adoptive preparedness. On the other hand, inability to take charge of what affects an individual's life leads to disincentives such as anxiety, apathy and desolation. However, behaviour can be changed. Almost half a century ago Festinger (1957), developed the cognitive dissonance theory to explain behavioural change process. The theory is based on three basic assumptions. First, people know when their actions are inconsistent with their beliefs. Secondly, the inconsistency triggers dissonance and motivates a person to seek resolution to the dissonance. Lastly, the dissonance can be resolved through change of belief, actions or perception of an action.

Behavioral change process as suggested by Festinger (1957) is influenced by principles of social cognitive theory. According to the theory, there are three factors (agencies) that influence an individual’s actions. These are; direct personal, proxy and collective agencies (Bandura, 2001). Direct personal agency is the capacity of a person to personally influence desired outcome while proxy agency is achieving an outcome through others. On the other hand, collective agency is a socially and interdependently-coordinated outcome. Understanding up-take process of ISNMT will also depend on principles of Unified Theory of Acceptance and Use of Technology (Venkatesh, 2012). Elements of the theory include performance (benefits derived from a technology) and effort (ease of use) expectancies, social influence (opinion from friends and family members) and facilitating conditions (perception of the availability of resources and support to use a technology).

2.7 Summary of the literature and research gap

Persistent soil fertility problem poses serious threat to current and future food production in Central Highlands of Kenya. Past soil fertility management attempts in solving the problem used mineral fertilizers and to-date, integrated approaches are encouraged. Organic inputs are important component of the integrated strategies. Tillage method is also becoming an important aspect of soil fertility management as it affects SOM and consequently other soil properties. However, how maize productivity responds to the mix of tillage method and organic inputs with or without mineral fertilizers in Central Highlands of Kenya has not sufficiently been considered. Moreover, with the increasing competing demand for crop residues as either goat feeds or soil amendments, much attention has been given to grain yield at the expense of above-ground biomass production. Though conditions at smallholder farms vary widely, less has been done to characterize rates of locally-available organic inputs such as goat manure and *Tithonia diversifolia*. Also, effect of *Dolichos lablab* on soil fertility has not been sufficiently studied in the study area.

Chapter 3

3.0 RESEARCH METHODOLOGY

3.1 Study area

The study was conducted in Gakuuni, Gakwegoni, Kangutu and Kathunguni villages in Chuka Division, Meru South sub-county, Tharaka-Nithi County and in Githunguri, Njabai, Rwaitira and Mithandukuini villages in Gatanga Division, Gatanga sub-county (Fig. 3.1), Muranga County. The choice of these study areas was guided by the project interest which was based on exploratory study that found out that several studies have been conducted on the selected organic resources management technologies but their adoptions have remained low.

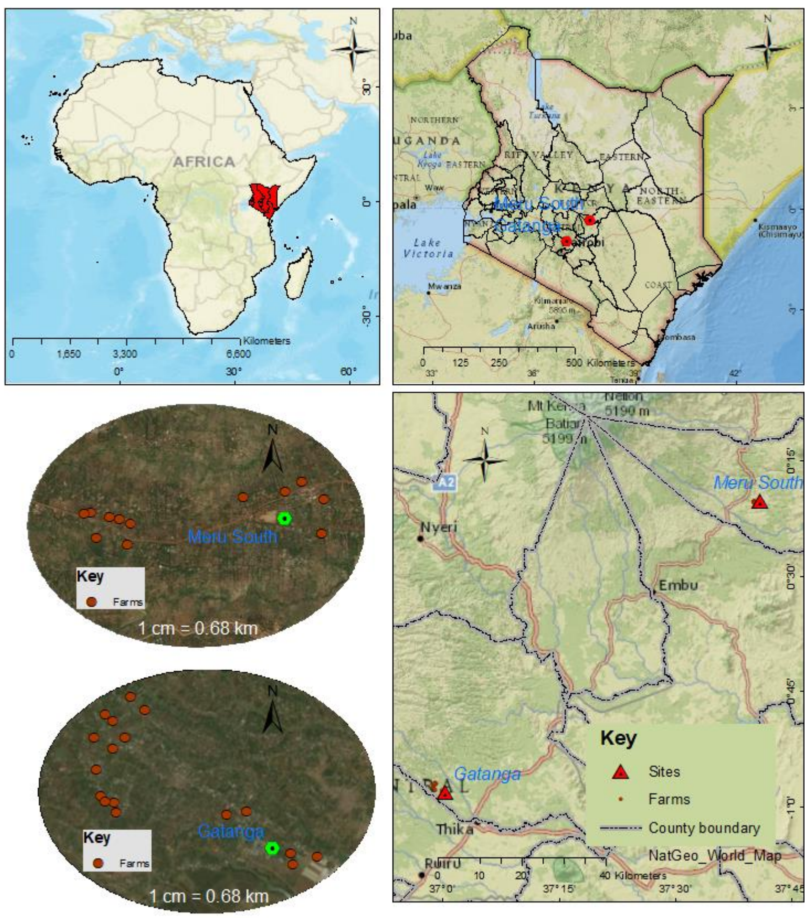

Figure 3:1: Map of the study sites

Meru South Sub-county is situated on the Eastern slopes of Mt. Kenya within Upper Midland Zone II (UM2), which is a predominantly coffee-growing zone, and Upper Midland Zone III (UM3), marginal coffee-growing zone agro-ecological zones (AEZ). The Sub-county lies at an altitude of 1,500 m above sea level (a.s.l) and receives a bimodal annual rainfall averaging between 600 to 1,200 mm (Jaetzold *et al*, 2007), with the long rains (LR) received from March to June and short rains (SR) from October to December and mean annual temperature range of 20 ^{o} C. Soils in the study area are deep and highly weathered with moderate to high inherent fertility (Jaetzold *et al*, 2007) classified as *Humic Nitisols* (IUSS Working Group WRB, 2014).

The farming system is dominated by livestock-crops, intensively practiced on small pieces of land averaging 2 ha for subsistence consumption. The main cash crops are; coffee (*Coffea arabica*), tea (*Camellia sinensis*) and avocado (*Persea americana*). Maize (*Zea mays* L.) is the staple food crop cultivated every cropping season and often intercropped with beans (*Phaseolus vulgaris*). Cassava (*Manihot esculenta*) and Irish potato (*Solanum tuberosum*) are the other common subsistence crops while banana (*Musa spp*.) is a dual crop (both a commercial and subsistent crop). Most farmers keep improved dairy cattle breeds as a primary enterprise. Other common livestock include poultry, goats and rabbits. Casual working and motorbike (boda boda) transportation business are common practices to supplement farming income. The Sub-county covers an area of 624.0 km^2, 128,107 individuals, population density of about 205 persons km^{-2} and 33,259 households (KNBS Report, 2013).

Gatanga Sub-county lies within five AEZs namely; Lower Highland I (LH1), tea growing and dairy keeping zone, Upper Highland I (UH1), sheep and dairy rearing zone, Upper Midland I (UM1), coffee and tea growing zone, Upper Midland II (UM2), main coffee growing zone, and Upper Midland III (UM3)- Marginal coffee growing zone (Jaetzold *et al*, 2007). The Sub-county is located at an altitude of 1,520-2,280 m a.s.l and receives a bimodal annual rainfall averaging between 900 to 1,400 mm (Jaetzold *et al*, 2007), with the long rains (LR) received from March to June and short rains (SR) from October to

December and mean annual temperature range of 26.3^{o}C. Soils are *Nitisols* which are deep and highly weathered with moderate to high inherent fertility (Jaetzold *et al*, 2007).

Mixed farming is the dominant farming system in Gatanga in which crops, livestock and agroforestry are practiced intensively on small pieces of land averaging 1.5 ha. The main cash crops are coffee (*Coffea arabica*) and tea (*Camellia sinensis*) while maize and beans (*Phaselous vulgaris*) are important staple food crops. Cassava (*Manihot esculenta*), sweet potatoes (*Ipomoea batatas*) and irish potato (*Solanum tuberosum*) are the other common subsistence crops while banana (*Musa spp*.) is a dual crop. Most farmers keep improved dairy cattle breeds as a primary enterprise. Other common livestock include poultry, sheep and goats. There are 163,597 people, out of which, 38.8% work for pay, 37.1% family agricultural holding and 4.8% unemployed and a population density of 362 persons per km^2 (KNBS Report, 2013).

3.2. Farmer selection and design of the on-farm experiment

Fifteen (15) and eighteen (18) farmers from Meru South and Gatanga, respectively, were randomly selected from a list of farmers obtained from the Ministry of Food and Agriculture extension officer in each site. Exploratory visits were conducted to the selected farmers' fields to establish their locations, assess soil fertility spatial variability, and to evaluate whether the fields were suitable for establishing the trials. To ensure homogeneity, farmers were selected based on prevailing tillage type practiced by the farmer, soil type, proximity to automatic rain gauges installed in nearby primary schools and farmer's willingness to participate in the study. During selection, farmers located within two-kilometer radius from the installed rain gauges and away from homesteads were considered. Before establishing field trials, the farmers were trained on the SNMTs after which, they chose the technologies to test in their farms. At the beginning of each season, the selected farmers were trained on trial implementation and management, agronomic practices, phonological observation, and data collection and recording. The on-farm experiment was implemented during long (LR2016) and short (SR2016) rain seasons in the year 2016.

The experiment was laid out in a randomized complete block design. Individual farmers implementing a given treatment acted as a replicate of the treatment. The treatments were replicated four times per study site. It was ensured that plots with the same treatments were as similar as possible. The treatments were two tillage methods, conventional and minimum, combined with selected soil fertility inputs. Soil fertility inputs were mineral fertilizer, rock phosphate, legume intercrop (*Dolichos lablab*), goat manure and *Tithonia diversifolia*. Crop residue (maize stover) was surface-applied as mulch to all plots except two, the control and the sole mineral fertilizer plots.

The control treatment was the combination of conventional tillage with zero input application (CON-C). The combination resulted in a total of fourteen (14) treatments (Table 3.1). Each farmer implemented two (2) treatments alongside a control treatment. The requirement that each farmer implemented a control resulted in more control treatments, hence the unbalanced design. To reduce variability, it was ensured that all farmers implementing similar treatments practiced similar agronomic practices. The study provided fertilizers, maize (Zea mays L.) H516, and *Dolichos lablab* to the farmers at the beginning of each season. Plot sizes were 4.5 m x 4.5 m in Meru South and 6 m x 4.5 m in Gatanga.

Table 3:1: Treatment combinations and fertilizers application rates

Treatments	Abbreviation	Mineral fertilizer application rate	
		N (Kg/Ha)	P (Kg/Ha)
Conventional Tillage Control	CON-C	0	0
Conventional Tillage + Mineral fertilizer	CON-Mf	60	90
Conventional Tillage + Crop residues + Mineral fertilizer	CON-RMf	60	90
Conventional Tillage + Crop residues + Mineral fertilizer + Goat manure	CON-RMfM	30	90
Conventional Tillage + Crop residues+*Tithonia diversifolia* + Phosphate rock	CON-RTiP	0	90
Conventional Tillage + Crop residues+ Goat manure + *Dolichos lablab*	CON-RML	0	0
Conventional Tillage + Crop residues + *Tithonia diversifolia* + Goat manure	CON-RTiM	0	0
Minimum Tillage -Control	MIN-C	0	0
Minimum Tillage + Mineral fertilizer	MIN-Mf	60	90
Minimum Tillage + Crop residues + Mineral fertilizer	MIN-RMf	60	90
Minimum Tillage + Crop residues + Mineral fertilizer + Goat manure	MIN-RMfM	30	90
Minimum Tillage + Crop residues +*Tithonia diversifol*ia + Phosphate rock	MIN-RTiP	0	90
Minimum Tillage + Crop residues + Goat manure + *Dolichos lablab*	MIN-RML	0	0
Minimum Tillage + Crop residues + *Tithonia diversifolia* + Goat manure	MIN-RTiM	0	0

3.2.1 Inputs application rates, and installation and management of the field experiment

The recommended N and P application rates for maize in the two study sites are 60 kg N ha^{-1} and 90 kg P ha^{-1}, respectively. The weights of *Tithonia diversifolia* and *Dolichos lablab* manure equivalent to 60 kg N ha^{-1} were calculated based on the laboratory analysis results leading to the application of 1.5 tons ha^{-1} and 2.86 tons ha^{-1}, respectively. Crop residue (maize stover) was surface-applied as mulch a week after seedling emergence, at the recommended rate of 5 tons ha^{-1}. For the phosphate rock-receiving treatments, used commercially obtained phosphate rock (27:29% P_2O_5, 36:38% CaO) was used. Mineral fertilizer, NPK 23:23:0, to supply 60 kg N ha^{-1} and partially the 90 kg P ha^{-1} was used. To augment the deficit P, applied Triple Super Phosphate (TSP) (0:46:0) was applied.

The farmers cleared the experimental plots and removed all weeds two weeks before planting. Conventional tillage plots were ploughed using hand hoe to a depth of 15 cm while minimum tillage plots were scrapped to a depth of 0-5cm using a machete to reduce weed population. Maize was planted at a spacing of 0.75 m x 0.50 m inter-row and intra-row, respectively. *Tithonia diversifolia* and *goat* manure were incorporated two weeks before planting to a depth of 15 cm in the soil during ploughing under conventional tillage (CT), while for minimum tillage experiments, *Tithonia diversifolia* and *goat* manure, the farmers restricted their incorporation within the planting holes.

Three maize seeds were placed per hill and thinned two weeks after planting back to two to obtain the recommended plant population density of 53,333 plants ha^{-1}. *Dolichos lablab* was planted a week after maize germination between maize rows for the treatments that had legume intercrop. Crop residue was surface applied after seedling emergence. Farmers kept the experimental plots weed-free through weeding. For treatments that had conventional tillage, weeding was done using a hand-hoe while for minimum tillage, weeds were hand-removed. Preventive pesticide (Buldock) was sprayed to control stem borers. It was ensured that field technicians were present during planting in each farm to ensure that the farmers used the right procedure for each implemented treatment. However, the farmers independently conducted the required agronomic practices, as per the training. The farmers were encouraged to adopt the best agronomic practices during crop growth. During harvest, it was ensured that the researcher was present in the field to supervise maize harvesting and data collection and recording.

3.3 Variables measured

To evaluate effect of integrated soil nutrients management technologies on soil physical and chemical properties, the variables measured included: soil organic carbon (SOC), pH, total nitrogen (N), phosphorus (P), potassium (K), aggregate stability and bulk density. Nutrient contents of goat manure and *T. diversifolia* were determined. Weight losses after decomposition were used to determine decomposition rates and patterns using litter bag approach. To determine effect of integrated soil nutrients management technologies on maize yield, the variables measured were grain and above-ground biomass yields of the crop. To assess the likelihood of the up-take of the selected integrated soil nutrients management technologies, an interview schedule was administered to target farmers. The interview schedule covered variables on; household demographics, land size, labour availability, ease of obtaining the organic inputs (OIs), ease of implementation and need for modification of the techniques among others (Appendix 1).

3.4 Sample collection

Core rings were used to collect soil samples at 0-10 cm and 10-20 cm depths for SOC determination while an auger was used to collect samples for other soil fertility parameters to a depth of 0-20 cm. All the soil samples were collected at the beginning and at the end of the experiment. Sampling was done two weeks prior to planting and immediately after harvesting for each of the two seasons. Most of past studies determine SOC on fixed depth basis without considering difference in bulk densities resulting from conventional and minimum tillage methods. This might lead to overestimation thus the need to use equivalent soil mass basis. Soil parameters will be therefore calculated on equivalent soil mass (ESM) basis using cubic spline method by Wendt and Hauser (2013).

Harvesting was done from net plots. The plots were obtained by discarding the first lines around plots. Only the second lines were harvested. Grains together with the cobs were weighed *in-situ* to determine wet weight, sun-dried to moisture content less than 15% and then threshed, weighed to determine grain dry weight. The dry weight was then corrected to 12.5% moisture content for standardization. Samples of above-ground biomass were obtained from net plots by randomly sampling five stovers cut at ground level, weighed *in situ*, sun-dried and dry weight measured.

The study used litterbag technique to assess litters decomposition and nutrient release patterns. Litterbags were made from muslin cloth with a mesh diameter of 0.99 mm to restrict entry of soil debris and larger soil organisms into the bags. The litterbags measured 12 cm by 8 cm. Goat manure and *T. diversifolia* equivalent to 10 g of dry weight were placed in the muslin litter-bags. The litter-bags were placed to a depth of 0-

0.15 m (topsoil) under conventional (CT) and minimum tillage (MT) methods within maize-based cropping system.

Litter-bags were placed 0.1 m apart within maize rows and their positions marked for ease of tracing. Litter type was considered the treatment thus the study followed randomized complete block design (RCBD). For each tillage method, the treatments were replicated four times in both study areas. After 14, 28, 42, 56, 70, and 84 days of placement, replicates of the two litters were randomly selected to determine decomposition and nutrient release patterns. At each sampling, litter-bags were separated, by hand, from any plant and soil debris and transported in cool box to the laboratory. The litters were then oven-dried at 60˚C for 24 hours. The oven-dried samples were weighed to determine the remaining litter mass. Thereafter, the samples were ground to conduct biochemical analysis. The samples were ashed for 2 hours at 600 °C to correct for possible contamination by mineral soil. Remaining nutrients at each sampling time was determined by multiplying ash-free samples by the concentration of respective nutrients. Litter mass loss was derived from the remaining litter mass and decomposition rate constant (ƙ) calculated using equations 1 and 2, respectively.

$$M_t = M_0 exp^{-ƙt} \qquad \text{Equation 1}$$

$$ƙ = -1 \left\{ \frac{ln\left(\frac{M_t}{M_O}\right)}{t} \right\} \qquad \text{Equation 2}$$

Where M_t is the remaining litter mass after time t (days), M_o is the initial litter mass, exp. is the exponential, *ln* is the natural log and ƙ is the decomposition rate parameter. The larger the ƙ, the faster the litter decomposition rate.

Interview schedule

To determine likelihood of farmers taking up the ISNMTs interviews were conducted using minimum data set interview schedules (Appendix 1) at the end of the experiment. The target population were the farmers involved in implementation of the ISNMTs experiment. The schedule was pre-tested using three farmers who did not take part in the final interviews. The interview scheduled was composed of: demographic, farming type, soil fertility management, labour information and socioeconomic issues.

3.4 Laboratory analyses

Laboratory analyses were done in Kenya Agriculture and Livestock Research Organization (Muguga Laboratories). Bulk density was analyzed using gravimetric method, N by Kjeldahl method, P by colorimetric method (Ryan *et al,* 2001) and K using flame photometer. Soil organic carbon was determined using modified Walkely and Black Method (Ryan *et al,* 2001) while pH meter was used to determine soil pH. Litterbags were retrieved, cleaned, dried at 65°C, contents emptied to conical flasks and weighed to obtain mass loss then analysed for various nutrients.

3.5 Data analysis

Maize yield, soil and litter data were subjected to analysis of variance (ANOVA) using General Linear Model (GLM) in SAS version 9.2 (SAS Institute Inc. 2008). Treatments means separation was done using Duncan multiple range test at $p<0.05$. For pair-wise comparisons of the start and end of the experiment soil data, paired t-test for pair-wise comparisons at $p<0.05$ was used. Least significant difference (LSD) was used to separate data means compared between different tillage methods Qualitative data obtained from interview schedules were entered and maintained in Ms Excel, coded, ordered in Tables, themes explaining likelihood of or otherwise, ISNMTs up-take formulated, and interpreted (Table 3.2).

Table 3:2: Descriptions used in the thematic analysis

Themes	Description
Awareness of the selected ISNMT improvement techniques	The theme included the farmers' ability to mention the selected soil fertility improvement techniques implemented during the study period and additional soil fertility improvement techniques they usually used.
Determinants of taking up selected soil fertility improvement techniques	The theme included the benefits and advantages that the farmers gained from implementing soil fertility improvement techniques, availability of labour, availability of non-farming income for the support of improving SF, experience of the farmer, farmers' assessment of their soil fertility status and availability of organic inputs.
Likelihood of future utilization of selected soil fertility strategies	The theme considered the willingness of the farmers to continue using the implemented soil fertility improvement techniques in future, modification of the techniques to ease implementation, implementation of the techniques by other farmers who were not members of the project and the involvement of family members on the implementation of the techniques.
Factors that can potentially limit the use of various soil fertility techniques	The theme considered the value attached to different crops by farmers, land tenure, disadvantages and challenges of various soil fertility improvement techniques.

3.6 Rainfall amounts and characteristics

The rainfall distribution during the study period in the two sites is shown in figure 3.2. The two cropping seasons (2016LR and 2016SR) had distinct rainfall patterns for both Meru South and Gatanga. Meru South had higher seasonal rainfall variation in which total 2016SR season rainfall (392.9 mm) was less than half the amount received in the 2016LR season (879.5 mm). Rainfall events were more frequent in the first half of April (beginning of 2016LR season) but improved in the last half of the month. The remainder of the season was characterized by scarce and poorly distributed rainfall. The 2016SR season had poorly distributed and scarce rainfall throughout the season.

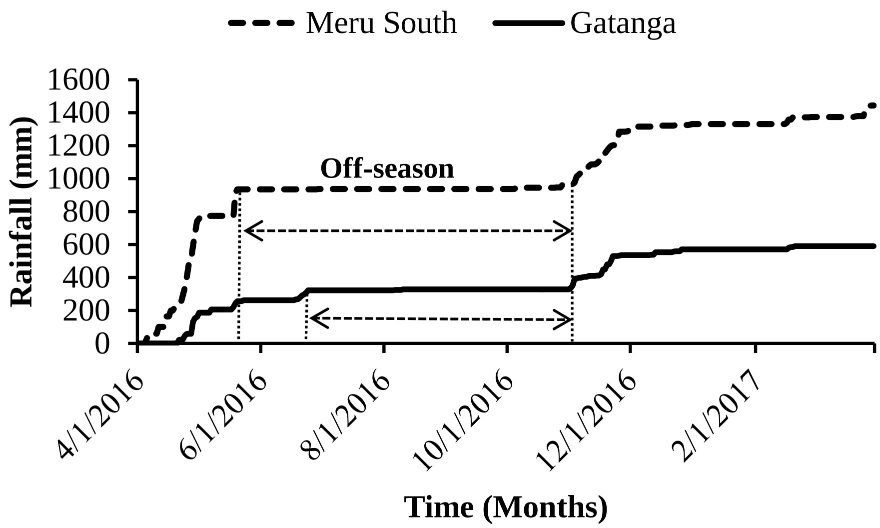

Figure 3:2: Cumulative rainfall for Meru South and Gatanga during 2016LR and 2016SR seasons

Gatanga received lower rainfall amounts in the two seasons compared to Meru South. However, it did not experience higher variations. The 2016SR had more than half (243.2 mm) total rainfall received in the 2016LR (328.7 mm). Rainfall amounts and distribution for the two seasons were poor throughout the study period.

Rainfall characteristic during 2016LR and 2016SR for Meru South and Gatanga are shown in Table 3.3. Rainfall onset delayed in the two seasons in Meru South but only in the 2016LR season in Gatanga where short rains began earlier compared to common long term observed onsets of long and short rains of 15th March and 15th October, respectively. Cessation dates varied markedly as the onset dates both in Meru South and Gatanga in the two seasons. As consequence of late onset and early cessation, Gatanga had the shortest length of the season (63 days) in the 2016LR. There was less number of dry spells in Gatanga than in Meru South probably due to the shorter seasons.

Table 3:3: Rainfall characteristics, onset dates, cessation dates, length of the season and numbers of dry spell days for Meru South and Gatanga sites during 2016LR and 2016SR seasons

	Season	
Rainfall characteristics	**2016LR**	**2016SR**
	Meru South	
On-set date	5th April	5th September
Cessation date	29th July	31st December
Length of season	79	116
Total rainfall (mm)	879.5	392.9
5-10 days	2	4
11-15 days	2	0
More than 15 days	1	2
Total dry spells	5	6
	Gatanga	
On-set date	21st April	06th October
Cessation date	24th June	26th December
Length of season	63	108
Total rainfall (mm)	328.7	243.2
5-10 days	1	1
11-15 days	1	1
More than 15 days	1	1
Total dry spells	3	3

Chapter 4

4.0 RESULTS

4.1 Effect of treatments on selected soil parameters

There were no significant (p=0.2866) differences between the initial and the final bulk densities across all the treatments in Meru South and so was the case in Gatanga (Table 4.1).

Table 4:1: Effects of treatments on initial, final and changes in bulk density (kg m^{-3}) in Meru South and Gatanga

Treatment	Meru South				Gatanga			
	Initial	**Final**	**Change**	**p-value**	**Initial**	**Final**	**Change**	**p-value**
CON-C	0.9758[a]	0.8722[a]	0.064	0.4251	1.0120[a]	0.9241[a]	-0.002	0.8609
CON-Mf	0.9958[a]	0.8509[a]	-0.032	0.2058	0.9612[a]	0.9062[a]	-0.058	0.2838
CON-RMf	0.9625[a]	0.7614[a]	-0.210	0.3734	0.9513[a]	0.8951[a]	-0.114	0.3372
CON-RMfM	1.0709[a]	0.8008[a]	-0.033	0.1276	0.9632[a]	0.8700[a]	-0.049	0.3841
CON-RML	0.9534[a]	0.6893[a]	-0.264	0.1030	1.0662[a]	0.7996[a]	-0.267	0.0741
CON-RTiM	0.9684[a]	0.8827[a]	-0.086	0.1433	1.0820[a]	0.8856[a]	-0.111	0.1443
CON-RTiP	0.949[a]	0.8526[a]	-0.096	0.0762	0.9686[a]	0.9255[a]	-0.043	0.238
MIN-C	0.9784[a]	0.8449[a]	-0.134	0.0512	0.9835[a]	0.9545[a]	-0.029	0.5285
MIN-Mf	0.9351[a]	0.7550[a]	-0.180	0.4036	1.0302[a]	0.8918[a]	-0.138	0.2369
MIN-RMf	0.9581[a]	0.7820[a]	-0.376	0.1193	1.0846[a]	0.9114[a]	-0.173	0.3436
MIN-RMfM	1.0166[a]	0.5824[a]	-0.235	0.4092	0.9978[a]	0.9505[a]	-0.047	0.5341
MIN-RML	0.9810[a]	0.8176[a]	-0.163	0.1080	0.9693[a]	0.8218[a]	-0.148	0.4027
MIN-RTiM	0.9749[a]	0.7402[a]	-0.235	0.0974	0.8797[a]	0.8706[a]	0.0351	0.5731
MIN-RTiP	1.0049[a]	0.9534[a]	-0.052	0.3163	1.0799[a]	0.9207[a]	-0.239	0.3356
p-value	***0.9205***	***0.2866***	***-***	***-***	***0.9398***	***0.0847***	***-***	***-***

Definition of abbreviated words: CON-C= conventional tillage (control), MIN-C= minimum tillage (control), CON-Mf= minimum tillage + mineral fertilizer, CON-RMf= minimum tillage + crop residues + mineral fertilizer, CON-RMfM= minimum tillage + crop residues + mineral fertilizer + goat manure, CON-RML= minimum tillage + crop residues + goat manure + legume intercrop, CON-RTiM= minimum tillage + crop residue + *Tithonia diversifolia* + goat manure, CON-RTiP= minimum tillage + crop residues + *Tithonia diversifolia* + rock phosphate. MIN-Mf= minimum tillage + mineral fertilizer, MIN-RMf= minimum tillage + crop residues + mineral fertilizer, MIN-RMfM= minimum tillage + crop residues + mineral fertilizer + goat manure, MIN-RML= minimum tillage + crop residues + goat manure + legume intercrop, MIN-RTiM= minimum tillage + crop residue + *Tithonia diversifolia* + goat manure, MIN_RTiP= minimum tillage + crop residues + *Tithonia diversifolia* + rock phosphate. Means with the same letter(s) within a column are not significantly different at $p \leq 0.05$.

In Meru South, all the treatments did not significantly influence soil parameters (total N, total P, K, Ca, pH, Mg, Mn, Cu, Fe, Zn and Na) both at the start and end of the experiment (Table 4.2 and 4.3) but there were significant changes on different parameters under various treatments (Table 4.6). Conventional tillage (CON-C) significantly recorded increase in total N ($p = 0.0034$) and Mn ($p = 0.0161$) but Ca and Cu decreased ($p = 0.0500$ and $p= 0.0411$, respectively). Convention tillage combined with mineral fertilizer significantly increased total N ($p = 0.0411$) but decreased Zn ($p = 0.0294$). Significant positive effect on N ($p = 0.0496$) and negative influence on Cu ($p = 0.0122$) and Zn ($p = 0.0253$) were recorded under CON-RML while CON-RMf also had a reduction effect on Cu ($p=0.0343$). Also, Zn was reduced ($p=0.0345$) under CON-RMfM. Slight but significant ($p=0.0424$) increase in N and Mn ($p=0.0309$) but decrease in Ca ($p= 0.0130$) and Zn ($p=0.0098$) were observed under CON-RTiM. On the other hand, CON-RTiP increased N ($p=0.0131$) and Mn ($p=0.0019$) significantly.

Total N ($p= 0.0161$) increased while Cu ($p=0.0007$) and Zn ($p=0.0219$) decreased significantly under MIN-C while MIN-Mf only affected total N ($p=0.0374$). However, there was increment in Mn ($p=0.0252$) and a reduction in Zn ($p=0.0443$) under MIN-RML. Significant changes were also observed under MIN-RMf in Cu, Fe and Zn ($p=0.0195$, $p=0.0374$ and $p=0.0388$, respectively). A significant reduction ($p=0.0488$) in Zn was recorded under MIN-RMfM. There was a significant reduction ($p=0.0390$) in Cu and an increment ($p=0.0332$) in Mn under MIN-RTiM and MIN-RTiP, respectively.

Table 4:2: Effects of treatments on total N (%), P (ppm), K (me%), Ca (me%), pH, Mg (me%), Mn (me%), Cu (ppm), Fe (ppm), Zn (ppm) and Na (ppm) the beginning of experiment in Meru South

Treatment	**N**	**P**	**K**	**Ca**	**pH**	**Mg**	**Mn**	**Cu**	**Fe**	**Zn**	**Na**
CON-C	0.100[a]	28.330[a]	1.313[a]	12.767[a]	5.903[a]	1.537[a]	0.140[a]	4.547[a]	28.867[a]	50.430[a]	0.7
CON-Mf	0.087[a]	40.000[a]	1.193[a]	11.300[a]	6.040[a]	1.470[a]	0.713[a]	3.660[a]	29.100[a]	52.570[a]	0.6
CON-RMf	0.090[a]	61.670[a]	1.420[a]	11.467[a]	6.047[a]	1.610[a]	0.287[a]	6.030[a]	46.000[a]	53.930[a]	0.713
CON-RMfM	0.095[a]	40.000[a]	0.960[a]	12.500[a]	5.955[a]	1.400[a]	0.570[a]	4.830[a]	33.050[a]	44.000[a]	0.46
CON-RML	0.103[a]	28.330[a]	1.047[a]	8.213[a]	5.677[a]	1.260[a]	0.683[a]	4.303[a]	30.433[a]	53.830[a]	0.513
CON-RTiM	0.085[a]	27.500[a]	1.220[a]	12.050[a]	6.420[a]	1.675[a]	0.135[a]	5.530[a]	30.000[a]	39.850[a]	0.66
CON-RTiP	0.107[a]	48.330[a]	1.480[a]	12.800[a]	5.650[a]	1.540[a]	0.237[a]	5.097[a]	40.800[a]	62.330[a]	0.767
MIN-C	0.097[a]	60.000[a]	1.247[a]	7.547[a]	5.900[a]	1.483[a]	0.173[a]	4.600[a]	36.267[a]	55.100[a]	0.593
MIN-Mf	0.090[a]	50.000[a]	1.330[a]	11.650[a]	5.910[a]	1.615[a]	0.435[a]	6.580[a]	35.650[a]	43.000[a]	0.72
MIN-RMf	0.090[a]	67.500[a]	1.270[a]	10.350[a]	5.740[a]	6.650[a]	0.520[a]	5.270[a]	38.100[a]	46.800[a]	0.62
MIN-RMfM	0.080[a]	52.500[a]	1.380[a]	11.500[a]	6.230[a]	6.965[a]	0.215[a]	6.690[a]	39.750[a]	42.600[a]	0.71
MIN-RML	0.115[a]	27.500[a]	1.300[a]	7.820[a]	5.815[a]	1.155[a]	0.225[a]	7.035[a]	26.800[a]	51.800[a]	0.65
MIN-RTiM	0.085[a]	47.500[a]	1.260[a]	7.620[a]	5.950[a]	1.370[a]	0.505[a]	3.615[a]	29.700[a]	48.350[a]	0.63
MIN-RTiP	0.120[a]	47.500[a]	1.270[a]	12.800[a]	5.935[a]	1.545[a]	0.225[a]	7.275[a]	29.000[a]	61.350[a]	0.63
p-value	***0.512***	***0.5751***	***0.5038***	***0.855***	***0.94***	***0.23***	***0.414***	***0.758***	***0.4249***	***0.8512***	***0.47***

Definition of abbreviated words: CON-C= conventional tillage (control), MIN-C= minimum tillage (control), CON-Mf= minimum tillage + mineral fertilizer, CON-RMf= minimum tillage + crop residues + mineral fertilizer, CON-RMfM= minimum tillage + crop residues + mineral fertilizer + goat manure, CON-RML= minimum tillage + crop residues + goat manure + legume intercrop, CON-RTiM= minimum tillage + crop residue + *Tithonia diversifolia* + goat manure, CON-RTiP= minimum tillage + crop residues + *Tithonia diversifolia* + rock phosphate. MIN-Mf= minimum tillage + mineral fertilizer, MIN-RMf= minimum tillage + crop residues + mineral fertilizer, MIN-RMfM= minimum tillage + crop residues + mineral fertilizer + goat manure, MIN-RML= minimum tillage + crop residues + goat manure + legume intercrop, MIN-RTiM= minimum tillage + crop residue + *Tithonia diversifolia* + goat manure, MIN_RTiP= minimum tillage + crop residues + *Tithonia diversifolia* + rock phosphate. Means with the same letter(s) within a column are not significantly different at $p \leq 0.05$.

Table 4:3: Effects of treatments on total N (%), P (ppm), K (me%), Ca (me%), pH, Mg (me%), Mn (me%), Cu (ppm), Fe (ppm), Zn (ppm) and Na (ppm) at the end of experiment in Meru South

Treatment	N	P	K	Ca	pH	Mg	Mn	Cu	Fe	Zn	Na
CON-C	0.157^{a}	22.000^{a}	0.727^{a}	7.700^{a}	5.957^{a}	1.337^{a}	1.540^{a}	2.517^{a}	36.730^{a}	10.080^{a}	0.453
CON-Mf	0.177^{a}	31.670^{a}	1.000^{a}	12.633^{a}	6.197^{a}	1.727^{a}	1.367^{a}	2.873^{a}	33.330^{a}	12.457^{a}	0.617
CON-RMf	0.170^{a}	55.330^{a}	0.960^{a}	12.633^{a}	6.033^{a}	1.960^{a}	1.440^{a}	1.257^{a}	33.200^{a}	13.533^{a}	0.533
CON-RMfM	0.235^{a}	53.180^{a}	1.550^{a}	14.300^{a}	6.300^{a}	2.540^{a}	0.970^{a}	1.295^{a}	20.350^{a}	10.550^{a}	0.95
CON-RML	0.193^{a}	40.670^{a}	1.580^{a}	14.800^{a}	6.387^{a}	2.967^{a}	1.120^{a}	1.357^{a}	31.670^{a}	7.500^{a}	0.83
CON-RTiM	0.160^{a}	32.000^{a}	0.520^{a}	7.150^{a}	5.915^{a}	1.775^{a}	1.680^{a}	1.670^{a}	41.900^{a}	8.875^{a}	0.54
CON-RTiP	0.157^{a}	32.330^{a}	1.067^{a}	10.033^{a}	5.580^{a}	2.230^{a}	1.257^{a}	1.633^{a}	38.070^{a}	7.573^{a}	0.633
MIN-C	0.123^{a}	40.670^{a}	1.040^{a}	10.600^{a}	5.917^{a}	2.127^{a}	0.913^{a}	2.113^{a}	50.230^{a}	11.467^{a}	0.583
MIN-Mf	0.175^{a}	35.000^{a}	0.840^{a}	4.850^{a}	5.650^{a}	2.625^{a}	1.465^{a}	2.690^{a}	50.650^{a}	14.050^{a}	0.525
MIN-RMf	0.160^{a}	43.500a	0.860^{a}	5.350^{a}	5.830^{a}	2.125^{a}	1.175^{a}	2.330^{a}	53.400^{a}	9.100^{a}	0.585
MIN-RMfM	0.185^{a}	35.500^{a}	0.990^{a}	5.900^{a}	6.075^{a}	2.770^{a}	0.955^{a}	2.040^{a}	45.100^{a}	6.420^{a}	0.615
MIN-RML	0.180^{a}	44.500^{a}	1.040^{a}	5.800^{a}	5.785^{a}	2.245^{a}	1.360^{a}	1.595^{a}	49.850^{a}	11.600^{a}	0.63
MIN-RTiM	0.210^{a}	49.000^{a}	1.250^{a}	5.550^{a}	6.050^{a}	2.285^{a}	1.185^{a}	1.740^{a}	47.100^{a}	11.800^{a}	0.515
MIN-RTiP	0.175^{a}	27.500^{a}	1.080^{a}	6.200^{a}	5.815^{a}	2.280^{a}	1.280^{a}	2.215^{a}	40.300^{a}	6.410^{a}	0.64
p-value	***0.325***	***0.8224***	***0.287***	***0.0545***	***0.879***	***0.691***	***0.108***	***0.934***	***0.2953***	***0.0917***	***0.44***

Definition of abbreviated words: CON-C= conventional tillage (control), MIN-C= minimum tillage (control), CON-Mf= minimum tillage + mineral fertilizer, CON-RMf= minimum tillage + crop residues + mineral fertilizer, CON-RMfM= minimum tillage + crop residues + mineral fertilizer + goat manure, CON-RML= minimum tillage + crop residues + goat manure + legume intercrop, CON-RTiM= minimum tillage + crop residue + *Tithonia diversifolia* + goat manure, CON-RTiP= minimum tillage + crop residues + *Tithonia diversifolia* + rock phosphate. MIN-Mf= minimum tillage + mineral fertilizer, MIN-RMf= minimum tillage + crop residues + mineral fertilizer, MIN-RMfM= minimum tillage + crop residues + mineral fertilizer + goat manure, MIN-RML= minimum tillage + crop residues + goat manure + legume intercrop, MIN-RTiM= minimum tillage + crop residue + *Tithonia diversifolia* + goat manure, MIN_RTiP= minimum tillage + crop residues + *Tithonia diversifolia* + rock phosphate. Means with the same letter(s) within a column are not significantly different at $p \leq 0.05$.

In Gatanga, the treatments significantly affected K and Na at the start of the experiment, and Mg and Na at the end (Table 4.4 and 4.5). The highest K was observed under CON-RML that out-performed CON-C and MIN-C by 64.45% and 4.68%, respectively. The lowest initial amount of K was recorded under MIN-RML. The initial Na and after-experiment Mg were highest under CON-RMfM. This was 51.90% and 5.00%, and 11.86% and 18.34% more than the Na and Mg amounts recorded under CON-C and MIN-C, respectively. However, at the end of the experiment, MIN-RMfM had the highest influence on Na. The treatment performed better as compared to CON-C and MIN-C by 41.80% and 66.20%, respectively. The lowest amount of the nutrient was obtained under CON-Mf while MIN-RTiM had the least influence on Mg.

Some treatments caused significant changes in various soil parameters (Table 4.7). There were significant changes on total N, Mn and Zn under CON-C. Only Mn and Zn increased and decreased significantly under CON-Mf while noticeable increase was recorded under CON-RML. There were also adjustments in Mg and Mn under CON-MfM and Mg, Mn and Cu under CON-RTIP. Additionally, Mg increased considerably while Zn decreased under CON-RTiP.

Significant changes were recorded in Mg, Mn and Cu under MIN-C as well as in Mg, Mn and Fe under MIN-Mf. Manganese and Na both increased under MIN-RML. Also, total N, Mn and Na increased while Zn decreased under MIN-RMf. Moreover, there were increments under MIN-RMfM in Ca, Mg, Mn and Na but reduction in Zn. Manganese and Fe increased but Cu decreased under MIN-RTiM. Manganese and Cu increased and decreased respectively, under MIN-RTiP.

Table 4:4: Effects of treatments on total N (%), P (ppm), K (me%), Ca (me%), pH, Mg (me%), Mn (me%), Cu (ppm), Fe (ppm), Zn (ppm) and Na (ppm) in the beginning of experiment in Gatanga

Treatment	**N**	**P**	**K**	**Ca**	**pH**	**Mg**	**Mn**	**Cu**	**Fe**	**Zn**	**Na**
CON-C	0.087[a]	33.330[a]	0.993[abc]	6.100[a]	5.263[a]	1.230[a]	0.230[a]	4.730[a]	35.100[a]	36.870[a]	0.553[ab]
CON-Mf	0.110[a]	31.670[a]	1.527[abc]	8.300[a]	5.307[a]	1.480[a]	0.563[a]	2.373[a]	36.133[a]	26.870[a]	0.820[ab]
CON-RMf	0.100[a]	67.500[a]	0.860[bc]	6.200[a]	5.570[a]	1.555[a]	0.390[a]	3.390[a]	43.300[a]	32.800[a]	0.510[b]
CON-RMfM	0.105[a]	55.000[a]	1.610[a]	10.100[a]	5.260[a]	1.510[a]	0.685[a]	3.385[a]	34.650[a]	41.400[a]	0.840[a]
CON-RML	0.097[a]	55.000[a]	1.633[a]	9.967[a]	5.803[a]	1.720[a]	0.570[a]	2.697[a]	32.867[a]	34.300[a]	0.800[ab]
CON-RTiM	0.093[a]	38.330[a]	1.013[abc]	5.867[a]	5.117[a]	1.293[a]	0.290[a]	4.660[a]	41.767[a]	37.130[a]	0.580[ab]
CON-RTiP	0.097[a]	35.000[a]	1.073[abc]	6.833[a]	5.380[a]	1.433[a]	0.453[a]	3.837[a]	29.933[a]	31.570[a]	0.607[ab]
MIN-C	0.103[a]	31.670[a]	1.560[ab]	9.700[a]	5.323[a]	1.380[a]	0.227[a]	3.310[a]	36.900[a]	50.100[a]	0.827[ab]
MIN-Mf	0.093[a]	16.670[a]	1.507[abc]	8.367[a]	5.070[a]	1.267[a]	0.340[a]	4.263[a]	37.367[a]	38.800[a]	0.800[ab]
MIN-RMf	0.087[a]	65.000[a]	0.940[abc]	5.533[a]	4.847[a]	1.367[a]	0.350[a]	8.720[a]	50.633[a]	49.730[a]	0.527[ab]
MIN-RMfM	0.103[a]	48.33[a]	1.433[abc]	9.500[a]	5.480[a]	1.357[a]	0.223[a]	3.217[a]	41.167[a]	55.130[a]	0.800[ab]
MIN-RML	0.105[a]	70.000[a]	0.830[c]	5.900[a]	5.005[a]	1.340[a]	0.395[a]	12.700[a]	43.100[a]	45.300[a]	0.500[b]
MIN-RTiM	0.085[a]	27.500[a]	1.010[abc]	7.800[a]	5.280[a]	1.335[a]	0.195[a]	3.350[a]	35.750[a]	51.800[a]	0.540[ab]
MIN-RTiP	0.097[a]	40.000[a]	1.620[a]	6.967[a]	5.510[a]	1.283[a]	0.350[a]	4.103[a]	30.467[a]	39.500[a]	0.827[ab]
p-value	***0.959***	***0.82***	***0.035***	***0.537***	***0.66***	***0.6***	***0.6106***	***0.235***	***0.625***	***0.246***	***0.043***

Definition of abbreviated words: CON-C= conventional tillage (control), MIN-C= minimum tillage (control), CON-Mf= minimum tillage + mineral fertilizer, CON-RMf= minimum tillage + crop residues + mineral fertilizer, CON-RMfM= minimum tillage + crop residues + mineral fertilizer + goat manure, CON-RML= minimum tillage + crop residues + goat manure + legume intercrop, CON-RTiM= minimum tillage + crop residue + *Tithonia diversifolia* + goat manure, CON-RTiP= minimum tillage + crop residues + *Tithonia diversifolia* + rock phosphate. MIN-Mf= minimum tillage + mineral fertilizer, MIN-RMf= minimum tillage + crop residues + mineral fertilizer, MIN-RMfM= minimum tillage + crop residues + mineral fertilizer + goat manure, MIN-RML= minimum tillage + crop residues + goat manure + legume intercrop, MIN-RTiM= minimum tillage + crop residue + *Tithonia diversifolia* + goat manure, MIN_RTiP= minimum tillage + crop residues + *Tithonia diversifolia* + rock phosphate. Means with the same letter(s) within a column are not significantly different at $p \leq 0.05$.

Table 4:5: Effects of treatments on total N (%), P (ppm), K (me%), Ca (me%), pH, Mg (me%), Mn (me%), Cu (ppm), Fe (ppm), Zn (ppm) and Na (ppm) in the beginning of experiment in Gatanga

Treatment	N	P	K	Ca	pH	Mg	Mn	Cu	Fe	Zn	Na
CON-C	0.150^{a}	40.670^{a}	1.100^{a}	5.567^{a}	5.617^{a}	3.473^{ab}	1.610^{a}	2.177^{a}	31.967^{a}	9.673^{a}	0.543^{c}
CON-Mf	0.123^{a}	38.000^{a}	1.213^{a}	7.967^{a}	5.293^{a}	2.413^{abc}	1.560^{a}	1.037^{a}	32.333^{a}	8.987^{a}	0.500^{c}
CON-RMf	0.140^{a}	20.000^{a}	1.100^{a}	9.200^{a}	6.040^{a}	3.415^{ab}	1.215^{a}	1.620^{a}	33.550^{a}	7.655^{a}	0.815^{bc}
CON-RMfM	0.135^{a}	46.500^{a}	1.450^{a}	12.300^{a}	5.975^{a}	3.885^{a}	1.525^{a}	1.550^{a}	24.050^{a}	9.560^{a}	0.890^{bc}
CON-RML	0.130^{a}	38.000^{a}	1.127^{a}	9.700^{a}	5.737^{a}	3.070^{abc}	1.173^{a}	1.1267^{a}	31.700^{a}	10.707^{a}	0.827^{bc}
CON-RTiM	0.140^{a}	29.670^{a}	1.087^{a}	8.433^{a}	5.503^{a}	2.930^{abc}	1.330^{a}	1.580^{a}	35.133^{a}	14.333^{a}	0.687^{bc}
CON-RTiP	0.117^{a}	26.330^{a}	1.280^{a}	9.167^{a}	5.640^{a}	2.633^{abc}	1.790^{a}	1.550^{a}	34.600^{a}	12.167^{a}	0.807^{bc}
MIN-C	0.127^{a}	30.330^{a}	1.287^{a}	11.833^{a}	5.980^{a}	3.283^{abc}	1.773^{a}	1.330^{a}	27.367^{a}	9.677^{a}	0.790^{bc}
MIN-Mf	0.160^{a}	58.330^{a}	1.280^{a}	13.733^{a}	6.060^{a}	3.190^{abc}	1.510^{a}	1.730^{a}	31.333^{a}	8.537^{a}	1.077^{ab}
MIN-RMf	0.117^{a}	27.330^{a}	0.953^{a}	9.433^{a}	5.363^{a}	2.900^{abc}	1.473^{a}	1.623^{a}	38.533^{a}	12.213^{a}	0.907^{bc}
MIN-RMfM	0.130^{a}	57.330^{a}	1.447^{a}	14.667^{a}	5.890^{a}	2.980^{abc}	1.130^{a}	1.033^{a}	32.800^{a}	9.733^{a}	1.313^{a}
MIN-RML	0.135^{a}	60.000^{a}	1.300^{a}	10.000^{a}	5.540^{a}	2.110^{abc}	1.460^{a}	2.100^{a}	52.600^{a}	13.350^{a}	0.825^{bc}
MIN-RTiM	0.115^{a}	31.500^{a}	0.910^{a}	7.500^{a}	5.220^{a}	1.600^{c}	1.735^{a}	1.510^{a}	61.000^{a}	13.200^{a}	0.605^{c}
MIN-RTiP	0.130^{a}	186.670^{a}	1.347^{a}	11.933^{a}	5.790^{a}	1.663^{c}	1.217^{a}	2.130^{a}	44.433^{a}	14.667^{a}	0.813^{bc}
p-value	***0.3339***	***0.0517***	***0.1135***	***0.1401***	***0.266***	***0.003***	***0.057***	***0.372***	***0.0778***	***0.4099***	***0.009***

Definition of abbreviated words: CON-C= conventional tillage (control), MIN-C= minimum tillage (control), CON-Mf= minimum tillage + mineral fertilizer, CON-RMf= minimum tillage + crop residues + mineral fertilizer, CON-RMfM= minimum tillage + crop residues + mineral fertilizer + goat manure, CON-RML= minimum tillage + crop residues + goat manure + legume intercrop, CON-RTiM= minimum tillage + crop residue + *Tithonia diversifolia* + goat manure, CON-RTiP= minimum tillage + crop residues + *Tithonia diversifolia* + rock phosphate. MIN-Mf= minimum tillage + mineral fertilizer, MIN-RMf= minimum tillage + crop residues + mineral fertilizer, MIN-RMfM= minimum tillage + crop residues + mineral fertilizer + goat manure, MIN-RML= minimum tillage + crop residues + goat manure + legume intercrop, MIN-RTiM= minimum tillage + crop residue + *Tithonia diversifolia* + goat manure, MIN_RTiP= minimum tillage + crop residues + *Tithonia diversifolia* + rock phosphate. Means with the same letter(s) within a column are not significantly different at $p \leq 0.05$.

Table 4:6: Changes on total N, P, K, Ca, pH, Mg, Mn, Cu, Fe, Zn and Na in Meru South

Treatment	N (%)	P (ppm)	K (me %)	Ca (me %)	pH	Mg (me %)	Mn (me %)	Cu (ppm)	Fe (ppm)	Zn (ppm)	Na (ppm)
CON-C	0.057(0.003)	-6.333(0.426)	-0.587(0.106)	-5.067(0.050)	0.053(0.801)	-0.200(0.649)	1.400(0.016)	-2.030(0.041)	7.867(0.352)	-40.353(0.079)	-0.247(0.243)
CON-Mf	0.090(0.016)	-8.333(0.507)	-0.193(0.299)	1.333(0.692)	0.157(0.528)	0.257(0.650)	0.653(0.104)	-0.787(0.597)	4.233(0.733)	-40.110(0.029)	0.017(0.845)
CON-RMf	0.080(0.057)	-6.333(0.357)	-0.460(0.089)	1.167(0.707)	-0.013(0.979)	0.350(0.173)	1.153(0.065)	-4.773(0.034)	-12.800(0.254)	-40.400(0.092)	-0.180(0.247)
CON-RMfM	0.140(0.134)	13.180(0.654)	0.590(0.308)	1.800(0.763)	0.345(0.188)	1.140(0.105)	0.400(0.410)	-3.535(0.087)	-12.700(0.396)	-33.450(0.035)	0.490(0.258)
CON-RML	0.090(0.05)	12.333(0.207)	0.533(0.303)	6.587(0.289)	0.710(0.213)	1.707(0.099)	0.437(0.089)	-2.947(0.012)	1.233(0.793)	-46.333(0.025)	0.317(0.223)
CON-RTiM	0.075(0.042)	4.500(0.500)	-0.700(0.177)	-4.900(0.013)	-0.505(0.382)	0.100(0.881)	1.545(0.031)	-3.860(0.394)	11.900(0.187)	-30.975(0.001)	-0.120(0.758)
CON-RTiP	0.050(0.013)	-16.000(0.197)	-0.413(0.192)	-2.767(0.487)	-0.120(0.699)	0.690(0.605)	1.020(0.002)	-3.463(0.102)	-2.733(0.685)	-54.760(0.059)	-0.133(0.432)
MIN-C	0.027(0.208)	-19.333(0.204)	-0.207(0.446)	3.053(0.247)	0.017(0.894)	0.643(0.290)	0.740(0.016)	-2.487(0.001)	13.967(0.102)	-43.633(0.022)	-0.010(0.939)
MIN-Mf	0.085(0.037)	-15.000(0.534)	-0.490(0.279)	-6.800(0.165)	-0.260(0.633)	1.010(0.149)	1.030(0.327)	-3.890(0.248)	15.000(0.051)	-28.950(0.093)	-0.195(0.466)
MIN-RMf	0.070(0.177)	-24.000(0.0001)	-0.410(0.623)	-5.000(0.344)	0.090(0.323)	-4.525(0.552)	0.655(0.269)	-2.940(0.012)	15.300(0.037)	-37.700(0.039)	-0.035(0.939)
MIN-RMfM	0.105(0.258)	-17.000(0.339)	-0.390(0.531)	-5.600(0.347)	-0.155(0.178)	-4.195(0.548)	0.740(0.102)	-4.650(0.217)	5.350(0.612)	-36.180(0.049)	-0.095(0.819)
MIN-RML	0.065(0.234)	17.000(0.366)	-0.260(0.386)	-2.020(0.767)	-0.030(0.951)	1.090(0.229)	1.135(0.025)	-5.440(0.355)	23.050(0.477)	-40.200(0.044)	-0.020(0.861)
MIN-RTiM	0.125(0.414)	1.500(0.889)	-0.010(0.990)	-2.070(0.742)	0.100(0.795)	0.915(0.288)	0.680(0.324)	-1.875(0.039)	17.400(0.379)	-36.550(0.055)	-0.115(0.471)
MIN-RTiP	0.055(0.272)	-20.000(0.605)	-0.190(0.100)	-6.600(0.142)	-0.120(0.656)	0.735(0.517)	1.055(0.033)	-5.060(0.343)	11.300(0.275)	-54.940(0.099)	0.010(0.921)

Definition of abbreviated words: CON-C= conventional tillage (control), MIN-C= minimum tillage (control), CON-Mf= minimum tillage + mineral fertilizer, CON-RMf= minimum tillage + crop residues + mineral fertilizer, CON-RMfM= minimum tillage + crop residues + mineral fertilizer + goat manure, CON-RML= minimum tillage + crop residues + goat manure + legume intercrop, CON-RTiM= minimum tillage + crop residue + *Tithonia diversifolia* + goat manure, CON-RTiP= minimum tillage + crop residues + *Tithonia diversifolia* + rock phosphate. MIN-Mf= minimum tillage + mineral fertilizer, MIN-RMf= minimum tillage + crop residues + mineral fertilizer, MIN-RMfM= minimum tillage + crop residues + mineral fertilizer + goat manure, MIN-RML= minimum tillage + crop residues + goat manure + legume intercrop, MIN-RTiM= minimum tillage + crop residue + *Tithonia diversifolia* + goat manure, MIN_RTiP= minimum tillage + crop residues + *Tithonia diversifolia* + rock phosphate. Means with the same letter(s) within a column are not significantly different at $p \leq 0.05$. Letters in brackets are p values.

Table 4:7: Changes on total N, P, K, Ca, pH, Mg, Mn, Cu, Fe, Zn and Na in Gatanga

Treatment	N (%)	P (ppm)	K (me %)	Ca (me %)	pH	Mg (me %)	Mn (me %)	Cu (ppm)	Fe (ppm)	Zn (ppm)	Na (ppm)
CON-C	0.063(0.019)	7.333(0.746)	0.107(0.246)	-0.533(0.677)	0.353(0.218)	2.243(0.016)	1.380(0.019)	-2.553(0.107)	-3.133(0.827)	-27.193(0.001)	-0.010(0.667)
CON-Mf	0.013(0.383)	6.333(0.773)	-0.313(0.386)	-0.333(0.900)	-0.013(0.934)	0.933(0.197)	0.997(0.031)	-1.337(0.082)	-3.800(0.350)	-17.880(0.042)	-0.320(0.156)
CON-RMf	0.040(0.401)	-47.500(0.324)	0.240(0.251)	3.000(0.540)	0.470(0.513)	1.860(0.095)	0.825(0.081)	-1.770(0.382)	-9.750(0.540)	-25.145(0.148)	0.305(0.230)
CON-RMfM	0.030(0.374)	-8.500(0.816)	-0.160(0.356)	2.200(0.340)	0.715(0.315)	2.375(0.039)	0.840(0.045)	-1.835(0.148)	-10.600(0.438)	-31.840(0.199)	0.050(0.605)
CON-RML	0.033(0.109)	-17.000(0.431)	-0.507(0.170)	-0.267(0.372)	-0.067(0.678)	1.350(0.009)	0.603(0.178)	-1.570(0.098)	-1.167(0.858)	-23.593(0.143)	0.027(0.859)
CON-RTiM	0.047(0.085)	-8.667(0.444)	0.073(0.235)	2.567(0.098)	0.387(0.184)	1.637(0.017)	1.040(0.003)	-3.080(0.031)	-6.633(0.056)	-22.800(0.009)	0.107(0.494)
CON-RTiP	0.020(0.438)	-8.667(0.611)	0.207(0.266)	2.333(0.128)	0.260(0.344)	1.200(0.007)	1.337(0.051)	-2.287(0.119)	4.667(0.283)	-19.400(0.015)	0.200(0.143)
MIN-C	0.023(0.073)	-1.333(0.914)	-0.273(0.288)	2.133(0.652)	0.657(0.104)	1.903(0.007)	1.547(0.007)	-1.980(0.002)	-9.533(0.371)	-40.423(0.053)	-0.037(0.487)
MIN-Mf	0.067(0.135)	41.667(0.332)	-0.227(0.649)	5.367(0.094)	0.990(0.096)	1.923(0.006)	1.170(0.013)	-2.533(0.075)	-6.033(0.035)	-30.263(0.084)	0.277(0.168)
MIN-RMf	0.030(0.035)	-37.667(0.228)	0.013(0.967)	3.900(0.227)	0.517(0.148)	1.533(0.082)	1.123(0.036)	-7.097(0.288)	-12.100(0.168)	-37.520(0.012)	0.380(0.025)
MIN-RMfM	0.027(0.287)	9.000(0.622)	0.013(0.900)	5.167(0.045)	0.410(0.232)	1.623(0.045)	0.907(0.010)	-2.183(0.003)	-8.367(0.272)	-45.400(0.007)	0.513(0.023)
MIN-RML	0.030(0.500)	-10.000(0.828)	0.470(0.172)	4.100(0.301)	0.535(0.475)	0.770(0.556)	1.065(0.027)	-10.600(0.380)	9.500(0.824)	-31.950(0.187)	0.325(0.001)
MIN-RTiM	0.030(0.374)	4.000(0.410)	-0.100(0.795)	-0.300(0.874)	-0.060(0.850)	0.265(0.534)	0.265(0.033)	1.540(0.035)	-1.840(0.029)	25.250(0.210)	0.065(0.835)
MIN-RTiP	0.033(0.109)	46.700(0.121)	-0.273(0.199)	4.967(0.220)	0.280(0.308)	0.380(0.061)	0.867(0.019)	-1.973(0.013)	13.967(0.131)	-24.833(0.103)	-0.013(0.895)

Definition of abbreviated words: CON-C= conventional tillage (control), MIN-C= minimum tillage (control), CON-Mf= minimum tillage + mineral fertilizer, CON-RMf= minimum tillage + crop residues + mineral fertilizer, CON-RMfM= minimum tillage + crop residues + mineral fertilizer + goat manure, CON-RML= minimum tillage + crop residues + goat manure + legume intercrop, CON-RTiM= minimum tillage + crop residue + *Tithonia diversifolia* + goat manure, CON-RTiP= minimum tillage + crop residues + *Tithonia diversifolia* + rock phosphate. MIN-Mf= minimum tillage + mineral fertilizer, MIN-RMf= minimum tillage + crop residues + mineral fertilizer, MIN-RMfM= minimum tillage + crop residues + mineral fertilizer + goat manure, MIN-RML= minimum tillage + crop residues + goat manure + legume intercrop, MIN-RTiM= minimum tillage + crop residue + *Tithonia diversifolia* + goat manure, MIN_RTiP= minimum tillage + crop residues + *Tithonia diversifolia* + rock phosphate. Means with the same letter(s) within a column are not significantly different at $p \leq 0.05$. Letters in brackets are p values.

4.1.2 Treatment effect on total soil organic carbon

The treatments did not significantly affect initial and final SOC (Table 4.8). However, the treatments explained 39.78% (R^2=0.3978) increase in SOC in Meru South and 26.55% (R^2=0.2655) in Gatanga. Significant changes were observed under CON-C, CON-RTiP, MIN-RMf, CON-RMf and CON-Mf in Meru South and only under CON-RML in Gatanga, which were 53%, 81%, 96%, 26% and 40%; and 33%, respectively, increment.

The initial highest total SOC was recorded in MIN-RML, which was 34.82% and 77.97% increase from CON-C and MIN-C, respectively in Meru South and in MIN-C treatment in Gatanga, which was 33.61% increment from the one, observed in CON-C. The lowest amount of organic carbon was observed under MIN-RMf which was 80.58 Mg ha^{-1} less than the amount recorded under CON-C and 36.88 Mg ha^{-1} under MIN-C in Meru South. Organic carbon in MIN-RMf was the lowest in Gatanga and was 78.22 Mg ha^{-1} and 26.59 Mg ha^{-1} lesser than the amounts observed in MIN-C and CON-C, respectively.

At the end of the experiment, CON-RTiP had the highest total SOC in Meru South. This was 18.17% and 68.63% up from the amounts registered in CON-C and MIN-C, respectively. The lowest organic carbon was observed in MIN-C. In Gatanga, CON-RML increased total SOC by 30.67% and 43.68% up from CON-C and MIN-C, correspondingly. Conversely, CON-RTiP had the lowest amount of organic carbon which was 80.70 Mg ha^{-1} and 54.40 Mg ha^{-1} less than amounts recorded in CON-C and MIN-C.

Table 4:8: Effects of treatments on initial, final and changes in soil organic carbon (Mg ha^{-1}) in Meru South and Gatanga

Treatment	Meru South				Gatanga			
	Initial	Final	Change	p-value	Initial	Final	Change	p-value
CON-C	180.23[a]	274.94[a]	94.71	0.0173	153.61[a]	290.53[a]	136.9	0.1054
CON-Mf	108.58[a]	360.95[a]	252.40	0.0351	200.63[a]	259.85[a]	59.22	0.5113
CON-RMf	141.51[a]	368.75[a]	227.20	0.0053	191.97[a]	337.21[a]	145.2	0.3422
CON-RMfM	221.82[a]	375.04[a]	153.20	0.2782	188.79[a]	285.38[a]	96.59	0.5138
CON-RML	202.70[a]	384.11[a]	181.40	0.1727	140.61[a]	379.64[a]	239	0.0191
CON-RTiM	130.84[a]	408.85[a]	278.00	0.1090	158.60[a]	336.39[a]	177.8	0.1077
CON-RTiP	178.97[a]	324.91[a]	145.90	0.0208	179.87[a]	209.83[a]	29.96	0.4207
MIN-C	136.53[a]	192.68[a]	56.15	0.1933	205.24[a]	264.23[a]	58.99	0.4729
MIN-Mf	140.11[a]	259.69[a]	119.60	0.3431	166.22[a]	273.63[a]	107.4	0.1280
MIN-RMf	99.65[a]	273.00[a]	173.30	0.0019	127.02[a]	253.37[a]	126.3	0.0919
MIN-RMfM	113.41[a]	358.22[a]	244.80	0.2724	183.45[a]	354.43[a]	171.0	0.1288
MIN-RML	242.98[a]	361.38[a]	118.40	0.3745	168.43[a]	314.44[a]	146.0	0.2342
MIN-RTiM	162.58[a]	228.67[a]	66.09	0.2844	137.18[a]	302.68[a]	165.5	0.0924
MIN-RTiP	242.81[a]	313.89[a]	71.08	0.2548	185.53[a]	338.76[a]	153.2	0.0501
p-value	***0.433***	***0.3003***	**-**	**-**	***0.7741***	***0.4767***	**-**	**-**

Definition of abbreviated words: CON-C= conventional tillage (control), MIN-C= minimum tillage (control), CON-Mf= minimum tillage + mineral fertilizer, CON-RMf= minimum tillage + crop residues + mineral fertilizer, CON-RMfM= minimum tillage + crop residues + mineral fertilizer + goat manure, CON-RML= minimum tillage + crop residues + goat manure + legume intercrop, CON-RTiM= minimum tillage + crop residue + *Tithonia diversifolia* + goat manure, CON-RTiP= minimum tillage + crop residues + *Tithonia diversifolia* + rock phosphate. MIN-Mf= minimum tillage + mineral fertilizer, MIN-RMf= minimum tillage + crop residues + mineral fertilizer, MIN-RMfM= minimum tillage + crop residues + mineral fertilizer + goat manure, MIN-RML= minimum tillage + crop residues + goat manure + legume intercrop, MIN-RTiM= minimum tillage + crop residue + *Tithonia diversifolia* + goat manure, MIN_RTiP= minimum tillage + crop residues + *Tithonia diversifolia* + rock phosphate.
Means with the same letter(s) within a column are not significantly different at $p \leq 0.05$.

The initial and final total organic carbon (p= 0.2149 and p= 0.1360, respectively) did not significantly vary between CON-C and MIN-C in Meru South (Fig. 4.1). Also, organic carbon did not significantly vary between the two tillage methods both at the initial sampling (p=0.2324) and end of experiment sampling (p=0.6930) in Gatanga (Fig. 4.1). There was more organic carbon in CON-C than in MIN-C in Meru South. The initial organic carbon was 180.23 Mg ha^{-1} and 136.53 Mg ha^{-1} while at the end of the study, the amount had risen to 274.94 Mg ha^{-1} and 192.68 Mg ha^{-1} under CON-C and MIN-C, respectively. On the other hand, SOC was not high in CON-C throughout as it was higher in MIN-C (205.24 Mg ha^{-1}) than in CON-C (153.61 Mg ha^{-1}) at the start of the experiment. At the end of the experiment CON-C had more (290.53 Mg ha^{-1}) total SOC than MIN-C (264.23 Mg ha^{-1}). There was significant change in total SOC under CON-C (p=0.0173) but not under MIN-C (p=0.1933) in Meru South. Nonetheless, there was no significant change under both CON-C (p=0.1054) and MIN-C (p=0.4729) in Gatanga. Generally there was more change in carbon in CON-C than in MIN-C in both sites.

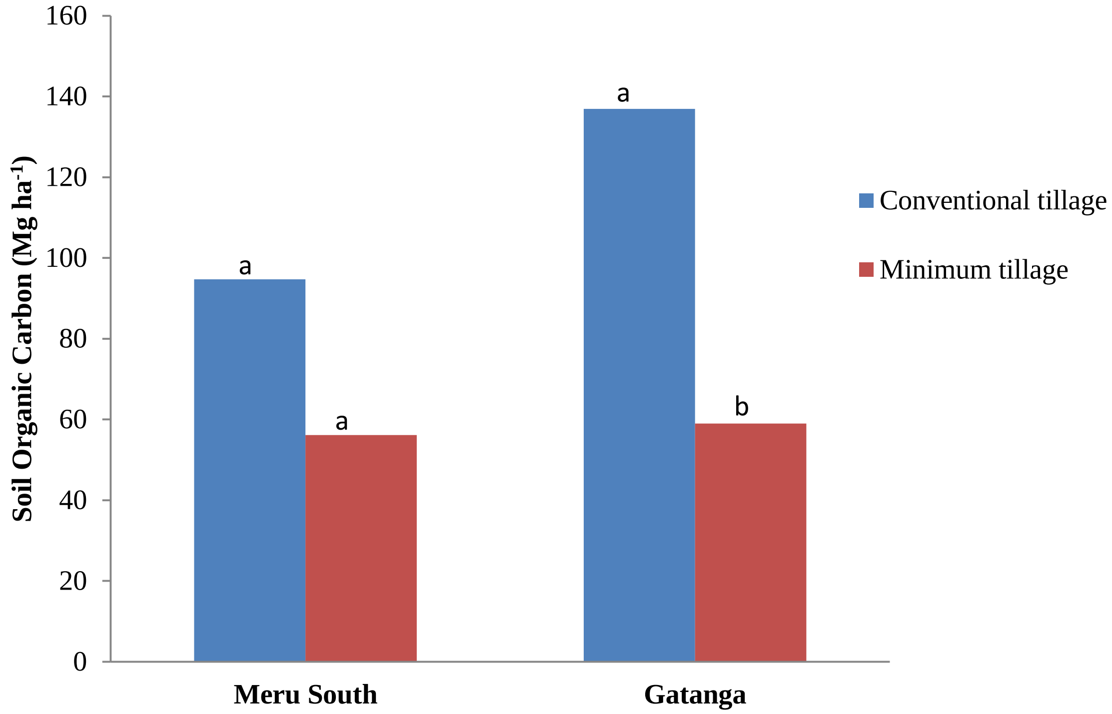

Figure 4:1: Change in SOC (Mg ha^{-1}) as affected by different tillage methods in Meru South and Gatanga

Means with the same letters are not statistically different

The Table 4.9 shows total SOC at 0-10 cm and 10-20cm depths. There were no significant differences in SOC across the treatments in Meru South and Gatanga. Nonetheless, the treatments explained 44.12% (R^2=0.4412) differences in SOC at 0-10cm and 52.55% (R^2=0.5255) at 10-20cm depths in Meru South. Also, the treatments had 35.25% (R^2=0.3525) and 46.28% (R^2=0.4628) influence on total SOC at the first and second soil profiles, respectively in Gatanga.

Table 4:9: Effects of treatments on soil organic carbon (Mg ha^{-1}) at 0-10cm and 10-20cm depths in Meru South and Gatanga

	Meru South		Gatanga	
Treatment	**0-10 cm**	**10-20 cm**	**0-10 cm**	**10-20 cm**
CON-C	274.94^{a}	292.73^{a}	290.53^{a}	308.61^{a}
CON-Mf	360.95^{a}	353.88^{a}	259.85^{a}	217.07^{a}
CON-RMf	368.75^{a}	283.15^{a}	337.21^{a}	356.13^{a}
CON-RMfM	375.04^{a}	366.42^{a}	285.38^{a}	259.92^{a}
CON-RML	384.11^{a}	355.11^{a}	379.64^{a}	275.67^{a}
CON-RTiM	408.85^{a}	397.44^{a}	336.39^{a}	210.80^{a}
CON-RTiP	324.91^{a}	287.54^{a}	209.83^{a}	179.40^{a}
MIN-C	192.68^{a}	167.20^{a}	264.23^{a}	261.91^{a}
MIN-Mf	259.69^{a}	215.37^{a}	273.63^{a}	310.76^{a}
MIN-RMf	273.00^{a}	233.36^{a}	253.37^{a}	209.70^{a}
MIN-RMfM	358.22^{a}	268.40^{a}	354.43^{a}	217.31^{a}
MIN-RML	361.38^{a}	306.15^{a}	314.44^{a}	248.82^{a}
MIN-RTiM	228.67^{a}	231.03^{a}	302.68^{a}	214.34^{a}
MIN-RTiP	313.89^{a}	325.23^{a}	338.76^{a}	244.54^{a}
p-value	***0.3003***	***0.1139***	***0.4767***	***0.1573***

Definition of abbreviated words: CON-C= Conventional tillage (control), MIN-C= minimum tillage (control), CON-Mf= minimum tillage + mineral fertilizer, CON-RMf= minimum tillage + crop residues + mineral fertilizer, CON-RMfM= minimum tillage + crop residues + mineral fertilizer + goat manure, CON-RML= minimum tillage + crop residues + goat manure + legume intercrop, CON-RTiM= minimum tillage + crop residue + *Tithonia diversifolia* + goat manure, CON-RTiP= minimum tillage + crop residues + *Tithonia diversifolia* + rock phosphate. MIN-Mf= minimum tillage + mineral fertilizer, MIN-RMf= minimum tillage + crop residues + mineral fertilizer, MIN-RMfM= minimum tillage + crop residues + mineral fertilizer + goat manure, MIN-RML= minimum tillage + crop residues + goat manure + legume intercrop, MIN-RTiM= minimum tillage + crop residue + *Tithonia diversifolia* + goat manure, MIN_RTiP= minimum tillage + crop residues + *Tithonia diversifolia* + rock phosphate. Means with the same letter(s) within a column are not significantly different at $p \leq 0.05$.

There were no significant differences (p=0.1360) in total SOC between the two tillage methods at 0-10 cm depth in Meru South but tillage explained 46.45% (R^2=0.4645) of the observed SOC difference (Fig. 4.2). However, significant variation (p=0.0218) was observed at 10-20 cm depth in which tillage explained 76.88% (R^2=0.7688) of the change in SOC. Generally, there was more SOC in CON-C than in MIN-C at the two depths. Conventional tillage (CON-C) had 82.26 Mg ha^{-1} and 125.53 Mg ha^{-1} more SOC than in MIN-C at 0-10 cm and 10-20 cm depths, respectively.

Conversely, SOC did not vary significantly between CON-C and MIN-C in Gatanga. At 0-10cm depth SOC was statistically the same at p=0.6930, tillage had only 4.31% (R^2= 0.0431) effect on the response variable (Fig. 4.2). Similarly, no significant difference (p=0.4208) in SOC was recorded at 10-20cm depth in which tillage method had just 16.72% (R^2=0.1672) influence on SOC. Same to Meru, conventional tillage had higher SOC than minimum tillage. The former tillage had 26.30 Mg ha^{-1} and 46.70 Mg ha^{-1} more SOC than the later tillage at 0-10cm and 10-20cm depths, respectively.

Gatanga had higher SOC at all the two depths and tillage methods than Meru South. Soil organic carbon recorded at the two depths were as follows; 274.94 Mg ha^{-1} and 292.73 Mg ha^{-1} under CON-C and 192.68 Mg ha^{-1} and 167.20 Mg ha^{-1} under MIN-C in Meru South while 290.53 Mg ha^{-1} and 308.61 Mg ha^{-1} under CON-C, 264.23 Mg ha^{-1} and 261.91 Mg ha^{-1} under MIN-C were recorded in Gatanga. At 0-10cm depth, there were 15.59 Mg ha^{-1} and 71.55 Mg ha^{-1} more of SOC in CON-C and MIN-C, respectively. At 10-20cm depth, the same was reported where SOC in CON-C and MIN-C was 15.88 Mg ha^{-1} and 2.32 Mg ha^{-1} lesser in Meru South than in Gatanga.

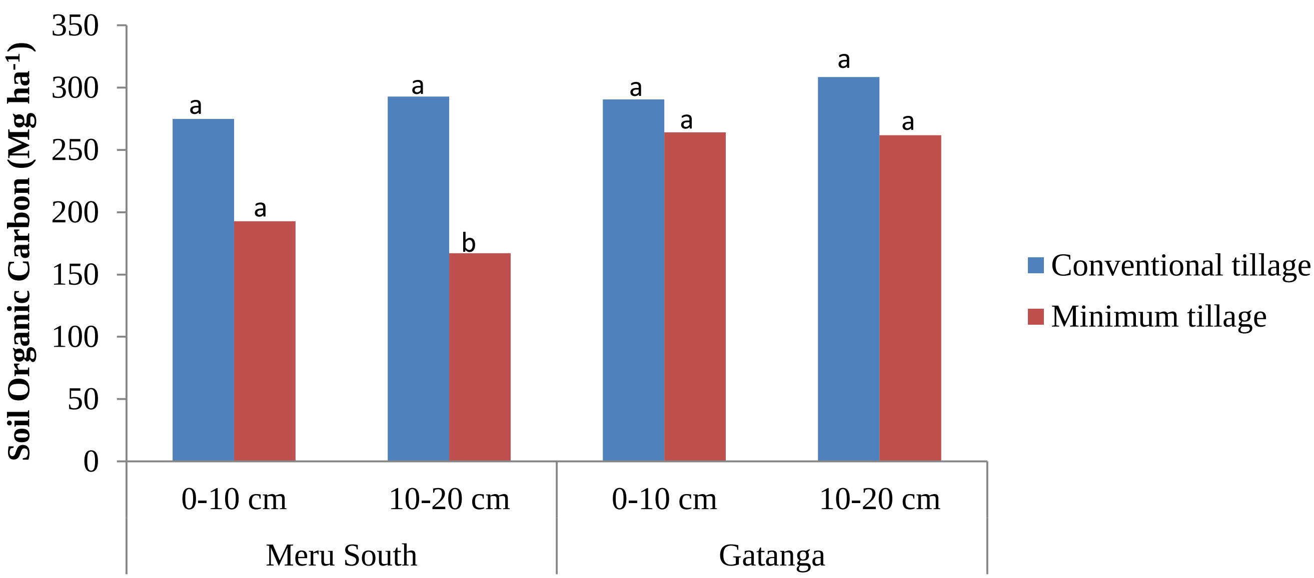

Figure 4:2: Effects of tillage on soil organic carbon (Mg ha^{-1}) at 0-10cm and 10-20cm depths in Meru South and Gatanga
Means with the same letters are not statistically different

4.2 Decomposability of organic inputs

4.2.1 Litter nutrients content

Goat manure and *T. diversifolia* differed in initial macro- and micro-nutrient contents (Table 4.10). *Tithonia diversifolia* had higher N, P, K, Ca, Mg, and Zn than goat manure. However, the manure generally had higher micro-nutrients than the *T. diversifolia*. Zinc, Copper and Manganese were higher in goat manure than were in *Tithonia diversifolia*.

Table 4:10: Initial macro- and micro-nutrients contents of goat manure and *Tithonia diversifolia*

Litter type	N (%)	P (%)	K (%)	Ca (%)	Mg (%)	Zn (mg/kg)	Cu (mg/kg)	Mn (mg/kg)	Zinc mg/kg
Manure	2.10	0.16	0.64	0.70	0.33	141	38.7	228	32.5
Tithonia diversifolia	3.85	0.28	2.56	0.96	0.34	26.3	27.7	110	59.0

4.2.1 Decomposition rates of organic inputs

Generally, goat manure had higher micro-nutrients than the *Tithonia diversifolia*. Zinc, Copper and Manganese were higher in goat manure than were in *Tithonia diversifolia*. *Tithonia diversifolia* had higher N, P, K, Ca, Mg, and Zn than goat manure (Table 4.10). Goat manure and *Tithonia diversifolia* exhibited same decomposition patterns but different decomposition rates during different days of retrieval in Meru South (Fig. 4.3). There were no significant differences in ƙ between goat manure and *Tithonia diversifolia* after 14, 28, 42, 56, 70 and 84 days after burying in Meru South. The two litters decomposed rapidly after 14 and 28 days and reached a peak after 56 days. *Tithonia diversifolia* decomposed faster than goat manure throughout the study period.

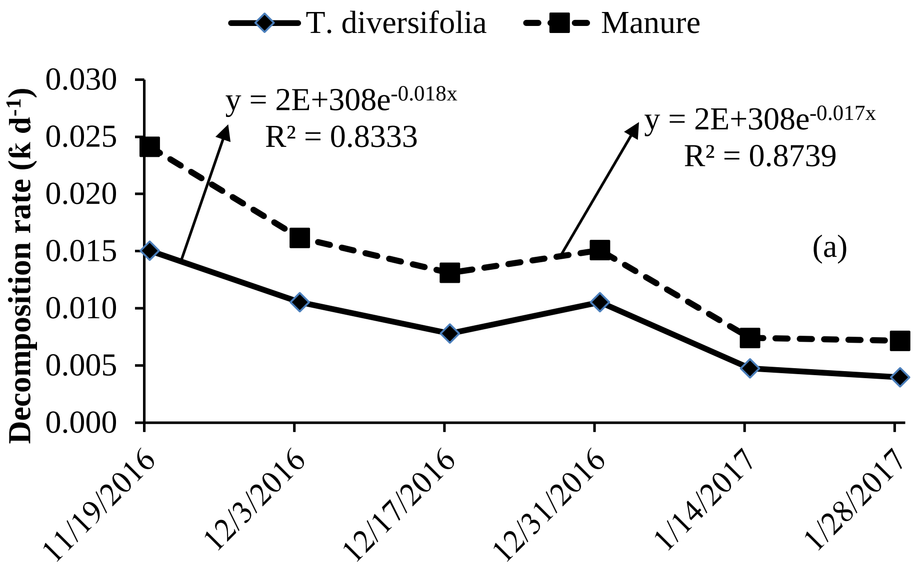

Figure 4:3: Decomposition rate constants (ƙ d^{-1}) for Meru South

In Gatanga, there were also no significant differences in ƙ between *Tithonia diversifolia* and goat manure after 14, 28, 42, 56, 70 and 84 days after burying (Fig. 4.4). However, the litters decomposed rapidly during the first 28 days after burying reaching a peak on the 56th day after burying then began to decline. *Tithonia diversifolia* had higher ƙ than goat manure throughout the study period.

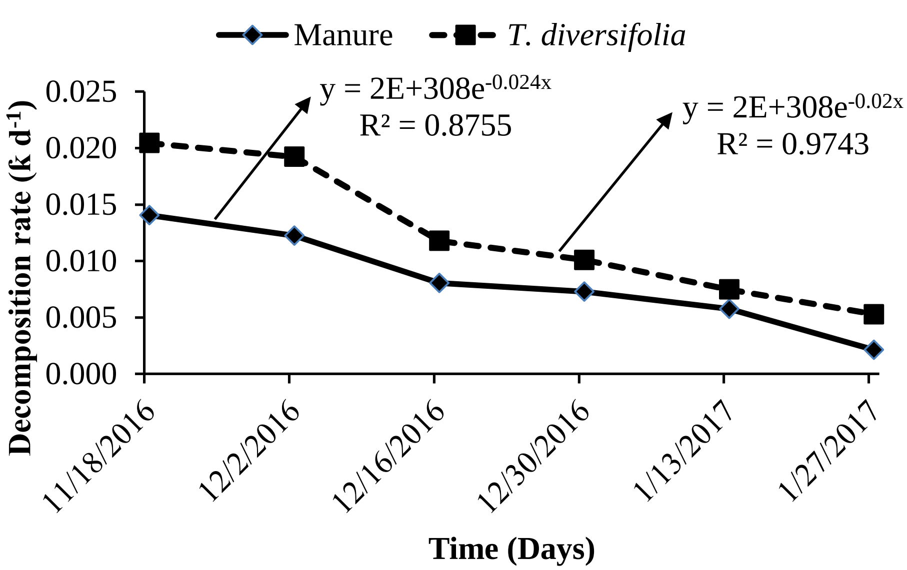

Figure 4:4: Decomposition rate constants (ƙ d^{-1}) for Gatanga

4.2.2 Remaining masses of organic inputs

Table 4.11 shows considerable amounts of mass lost by goat manure and *T. diversifolia* during different sampling times but the inputs had not completely decomposed at the end of the study. Mass loss between *T. diversifolia* and manure significantly varied after 14 and 42 days of retrieval (p=0.0081, and p=0.0308), respectively. Fourteen days after the inputs were incorporated into the soil, *T. diversifolia* had lost 22.43% of its mass, 17.29% more than the mass goat manure had lost. At the 2nd, 3rd, 4th and 5th retrieval days, percentage mass lost relative to the initial masses was 50.48, 60.18, 74.09 and 74.21 for goat manure, and 55.51, 73.22, 77.37 and 82.57 for *T. diversifolia*. At the end of the experiment, *T. diversifolia* and goat manure had lost 83.92 %and 77.45 %, respectively, of their masses.

Table 4:11: Percentage (%) remaining mass of goat manure and *Tithonia diversifolia* after different sampling days

	Litter type	
Days	**Manure**	***T. diversifolia***
14	77.57 (11.04)	60.28 (14.50)
28	49.52 (8.12)	44.49 (11.28)
42	39.82 (12.36)	26.78 (4.37)
56	25.91 (11.78)	22.63 (10.54)
70	25.79 (9.07)	17.43 (5.50)
84	22.56 (5.91)	16.08 (9.50)

Letters in brackets are standard deviations

4.2.3 Percent remaining nitrogen, phosphorus and potassium

In Meru South, percentage remaining N, P and K in *Tithonia diversifolia* and goat manure significantly varied (Table 4.12). Remaining N in *Tithonia diversifolia* and goat manure significantly differed on the 14th (p= 0.031) and 42nd (p =0.0017) days after burying. On the other hand, P significantly varied on the 14th (p= 0.0001), 42nd (p= 0.0002) and 70th (p= 0.0001) days after burying while K significantly differed after 14th (p= 0.0002), 28th (p= 0.0003), 42nd (p =0.0335), 70th (p= 0.0281) and 84th (p= 0.0035) days after burying.

In Gatanga, remaining N, P and K in *Tithonia diversifolia* and goat manure significantly varied during different days after burying (Table 4.12). Remaining N in *Tithonia diversifolia* and goat manure significantly differed on the 14th (p= 0.0036), 28th (p= 0.0022) and 56th (p =0.0164) days after burying while P significantly varied on the 14th (p= 0.0021), 28th (p= 0.0001), 56th (p= 0.0021), 70th (p= 0.0002) and 84th (p= 0.0042) days after burying. Potassium significantly differed between goat manure and *Tithonia diversifolia* after 14th (p= 0.0380), 56th (p=0.0443) and 70th (p= 0.0189) and days after burying.

Table 4:12: Percentage (%) remaining nitrogen (N), phosphorus (P) and potassium (K) in Meru South and Gatanga

Time (Days)	Litter	Meru South			Gatanga		
		N	P	K	N	P	K
14	Goat manure	63.84[a]	63.57[a]	77.34[a]	62.92[a]	67.86[a]	63.83[a]
	Tithonia diversiolia	58.33[b]	56.41[b]	61.65[b]	56.54[b]	64.92[b]	56.25[b]
	p value	0.031	0.0001	0.0002	0.0036	0.0021	0.038
28	Goat manure	59.01[a]	57.14[a]	58.66[a]	54.68[a]	63.57[a]	52.54[a]
	Tithonia diversiolia	58.19[a]	56.31[b]	47.91[b]	51.28[b]	59.15[b]	51.95[a]
	p value	0.8631	0.1591	0.0003	0.0022	0.0001	0.1312
42	Goat manure	56.23[a]	56.43[a]	45.39[a]	53.64[a]	61.31[a]	45.18[a]
	Tithonia diversiolia	53.76[b]	53.53[b]	36.19[b]	51.06[a]	59.13[a]	44.86[a]
	p value	0.0017	0.0002	0.0335	0.1041	0.6378	0.2829
56	Goat manure	48.57[a]	54.76[a]	35.00[a]	50.56[a]	53.57[a]	38.70[a]
	Tithonia diversiolia	47.96[a]	53.42[a]	34.98[a]	38.31[b]	50.45[b]	35.21[b]
	p value	0.0616	0.1241	0.3569	0.0164	0.0021	0.0443
70	Goat manure	38.53[a]	51.79[a]	34.92[a]	50.04[a]	51.19[a]	14.20[a]
	Tithonia diversiolia	36.89[a]	39.38[b]	14.43[b]	29.83[b]	48.61[b]	7.47[b]
	p value	0.2673	0.0001	0.0281	0.0003	0.0002	0.0189
84	Goat manure	17.36[a]	29.17[a]	34.44[a]	46.65[a]	21.43[a]	3.84[a]
	Tithonia diversiolia	15.75[a]	28.38[a]	14.17[b]	27.42[b]	18.17[b]	2.97[a]
	p value	0.5271	0.1799	0.0035	0.0170	0.0042	0.9900

Means within the same column with the same letter are not significantly different at $p \leq 0.05$.

4.3 Maize above-ground biomass yield as influenced by the selected ISNM technologies

4.3.1 Maize grain yield

Maize grain yield did not significantly vary among treatments during 2016LR but did during 2017SR season in Meru South (Table 4.13). Minimum tillage combined with crop residues, mineral fertilizer and goat manure performed the best in 2016LR season. The treatment increased grain yields by 78 and 57 % compared to the control treatments. In contrast, MIN-RTiP had the highest yield in the subsequent season and accounted for 75% and 93% increment production from the yields obtained in conventional and minimum tillage controls, respectively. Apart from MIN-RTiP, MIN-Mf, MIN-RMf and MIN-RMfM, all the remaining treatments did not significantly perform better than the conventional tillage control (CON-C) during 2016SR. On the other hand, minimum tillage control (MIN-C) did not perform significantly different only to MIN-RTiP treatment but significantly influenced grain yield as the other treatments.

Significant differences were observed in maize grain yield among treatments in Gatanga sub-county during the two seasons (Table 4.13). In the 2016LR season, MIN-RTiP had the highest yield. It increased grain production by 37% to 50% compared to control treatments. In 2016SR, MIN-RTiP still had the highest grain yield and improved yields by 75% and 120% from CON-C and MIN-C, respectively.

Table 4:13: Effect of various treatments on maize grain yields (Mg ha^{-1}) in Meru South and Gatanga Sub-counties during the 2016LR and 2016SR seasons, respectively

Treatment	Site			
	Meru South		Gatanga	
	2016LR	2016SR	2016LR	2016SR
CON-C	0.761^{a}	0.028^{d}	0.238^{b}	0.006^{c}
CON-Mf	1.510^{a}	0.079^{cd}	0.345^{b}	0.015^{c}
CON-RMf	1.420^{a}	0.086^{cd}	1.077^{ab}	0.017^{c}
CON-RMfM	2.007^{a}	0.144^{abcd}	1.392^{ab}	0.029^{c}
CON-RML	1.385^{a}	0.061^{cd}	0.481^{b}	0.017^{c}
CON-RTiM	1.747^{a}	0.101^{bcd}	1.441^{ab}	0.023^{c}
CON-RTiP	1.546^{a}	0.129^{abcd}	1.112^{ab}	0.045^{c}
MIN-C	1.117^{a}	0.060^{cd}	1.154^{ab}	0.012^{c}
MIN-Mf	2.225^{a}	0.187^{abc}	2.137^{ab}	0.123^{ab}
MIN-RMf	2.876^{a}	0.220^{ab}	1.434^{ab}	0.126^{ab}
MIN-RMfM	2.463^{a}	0.188^{abc}	1.643^{ab}	0.095^{b}
MIN-RML	2.237^{a}	0.061^{cd}	1.905^{ab}	0.020^{c}
MIN-RTiM	1.181^{a}	0.095^{bcd}	1.802^{ab}	0.041^{c}
MIN-RTiP	1.474^{a}	0.236^{a}	2.737^{a}	0.156^{a}
p-value	***0.0989***	***0.0021***	***0.0269***	***0.0001***

Definition of abbreviated words: CON-C= conventional tillage (control), MIN-C= minimum tillage (control), CON-Mf= minimum tillage + mineral fertilizer, CON-RMf= minimum tillage + crop residues + mineral fertilizer, CON-RMfM= minimum tillage + crop residues + mineral fertilizer + goat manure, CON-RML= minimum tillage + crop residues + goat manure + legume intercrop, CON-RTiM= minimum tillage + crop residue + *Tithonia diversifolia* + goat manure, CON-RTiP= minimum tillage + crop residues + *Tithonia diversifolia* + rock phosphate. MIN-Mf= minimum tillage + mineral fertilizer, MIN-RMf= minimum tillage + crop residues + mineral fertilizer, MIN-RMfM= minimum tillage + crop residues + mineral fertilizer + goat manure, MIN-RML= minimum tillage + crop residues + goat manure + legume intercrop, MIN-RTiM= minimum tillage + crop residue + *Tithonia diversifolia* + goat manure, MIN_RTiP= minimum tillage + crop residues + *Tithonia diversifolia* + rock phosphate. Means with the same letter(s) within a column are not significantly different at $p \leq 0.05$.

4.3.2 Maize Stover yield

Maize stover yield significantly varied among treatments in Meru South sub-county during the two seasons (Table 4.14). In 2016LR season, the highest yield was observed in MIN-Mf treatment which was not statistically different to the stover yield observed under MIN-RMf and MIN-RMfM treatments but varied with the yields recorded in the other treatments. In comparison to the control treatments, MIN-Mf increased the yield by 63% to 85%. The least yield was obtained under CON-C, and significantly differed with the yields under MIN-Mf, MIN-RMf and MIN-RMfM treatments but was not statistically different with the yields recorded under the other treatment. In 2016SR season, the highest yield was recorded under MIN-RMfM treatment and improved stover production by 45% - 75%. Statistically similar yields to yield recorded under MIN-RMfM treatment were observed under MIN-RTiP, MIN-RMf and CON-Mf. Nonetheless, the least yield was obtained under CON-C.

Stover yield was significantly affected by the treatments during the 2016LR and 2016SR seasons in Gatanga. The highest yield was reported under MIN-Mf during the 2016LR season. The treatment performed arguably better than most of the other treatments. The highest yield observed under MIN-Mf treatment was 53% and 37% increase from the yields recorded under CON-C and MIN-C treatments, respectively. The least yield was recorded under CON-C treatment (Table 4.14). In the 2016SR season, the short rain season of 2016, the highest yield was recorded in CON-RMf treatment, which was over 40% and, 80% of the yield observed during the first season under CON-C and MIN-C treatments.

Table 4:14: Effect of treatments on maize stover yields (Mg ha^{-1}) in Meru South and Gatanga during the 2016LR and SR2017SR seasons

Treatment	**Site**			
	Meru South		**Gatanga**	
	2016LR Season	**2016SR Season**	**2016LR Season**	**2016SR Season**
CON-C	0.039^{d}	0.012^{d}	0.032^{d}	0.032^{c}
CON-Mf	0.113^{bcd}	0.115^{abcd}	0.063^{cd}	0.111^{abc}
CON-RMf	0.089^{bcd}	0.049^{bcd}	0.069^{bcd}	0.210^{a}
CON-RMfM	0.167^{bcd}	0.101^{bcd}	0.057^{cd}	0.089^{bc}
CON-RML	0.171^{bcd}	0.103^{bcd}	0.153^{abc}	0.155^{ab}
CON-RTiM	0.125^{bcd}	0.074^{bcd}	0.157^{abc}	0.153^{ab}
CON-RTiP	0.063^{cd}	0.087^{bcd}	0.121^{abcd}	0.091^{bc}
MIN-C	0.043^{d}	0.044^{bcd}	0.060^{cd}	0.050^{bc}
MIN-Mf	0.371^{a}	0.097^{bcd}	0.202^{a}	0.137^{abc}
MIN-RMf	0.223^{abc}	0.154^{abc}	0.097^{abcd}	0.160^{ab}
MIN-RMfM	0.234^{ab}	0.222^{a}	0.192^{a}	0.137^{abc}
MIN-RML	0.171^{bcd}	0.101^{bcd}	0.122^{abcd}	0.106^{abc}
MIN-RTiM	0.079^{bcd}	0.037^{cd}	0.164^{abc}	0.101^{abc}
MIN-RTiP	0.199^{bcd}	0.157^{ab}	0.178^{ab}	0.075^{bc}
p-value	***0.0006***	***0.0032***	***0.0001***	***0.0007***

Definition of abbreviated words: CON-C= conventional tillage (control), MIN-C= minimum tillage (control), CON-Mf= minimum tillage + mineral fertilizer, CON-RMf= minimum tillage + crop residues + mineral fertilizer, CON-RMfM= minimum tillage + crop residues + mineral fertilizer + goat manure, CON-RML= minimum tillage + crop residues + goat manure + legume intercrop, CON-RTiM= minimum tillage + crop residue + *Tithonia diversifolia* + goat manure, CON-RTiP= minimum tillage + crop residues + *Tithonia diversifolia* + rock phosphate. MIN-Mf= minimum tillage + mineral fertilizer, MIN-RMf= minimum tillage + crop residues + mineral fertilizer, MIN-RMfM= minimum tillage + crop residues + mineral fertilizer + goat manure, MIN-RML= minimum tillage + crop residues + goat manure + legume intercrop, MIN-RTiM= minimum tillage + crop residue + *Tithonia diversifolia* + goat manure, MIN_RTiP= minimum tillage + crop residues + *Tithonia diversifolia* + rock phosphate. Means with the same letter(s) within a column are not significantly different at $p \leq 0.05$.

4.4 Assessment of likelihood of selected technologies uptake

4.4.1 Demographic characteristics

Demographic characteristics of the respondents are shown in Table 4.15. Gender of the respondents was fairly distributed in both sites but males dominated over females. In contrast, the gender of household heads (HH) differed widely. The study revealed that the males formed the majority (n=11, 84.6% and n=14, 77.8%) of household heads while females only headed a minority of families in Meru South and Gatanga, respectively. Two farmers in Meru South (constituting about 15 %) were single, another r two (15 %) were divorced and one (about 8%) was widowed. Similarly in Gatanga, fourteen of the respondents were married (77.8%), while 2 (11 %)) were widows, 1 (5.6%) was single and 1 was (5.6%) was divorced.

The findings of the study revealed that farming was the major occupation of the respondents in Meru South (n=8) and Gatanga (n=14) (Table 4.15). Other respondents engaged in occupations such as personal businesses, masonry and casual labour in Meru South (n=4) and Gatanga (n=2). Only a few respondents were employed in Gatanga (n=2) and Meru South (n=1).. The majority of respondents in Meru South (n=8) had attended secondary education, 4had upper primary education and few (n=1) had attained tertiary education. Similarly in Gatanga, the majority (n=7) of the respondents had secondary education followed by those who had upper primary education (n=6). However, some respondents (n=2) had not attained any level of education while others (n=2) dropped out at lower primary. The minority (n=1) of the respondents had attained tertiary education.

Table 4:15: Demographic characteristics of Meru South and Gatanga interviewed farmers

Demographic characteristics	**Site**		
	Meru South	**Gatanga**	**Total**
Gender of respondent			
Male	7(53.8%)	10 (55.6)	17 (54.84%)
Female	6 (46.2%)	8 (44.4%)	14 (45.16%)
Total	*13 (100%)*	*18 (100%)*	*31 (100%)*
Gender of household head (HH)			
Male	11 (84.6%)	14 (77.8%)	25 (80.65%)
Female	2(15.4%)	4 (22.2%)	6 (19.35%)
Total	*13 (100%)*	*18 (100%)*	*31 (100%)*
Marital status			
Single	2 (15.4%)	1 (5.6%)	3 (9.68%)
Married	8 (61.5%)	14 (77.8%)	22 (70.97%)
Divorced	2 (15.4%)	1 (5.6%)	3 (9.68%)
Widow	1 (7.7%)	2 (11.1%)	3 (9.68%)
Total	*13 (100%)*	*18 (100%)*	*31 (100%)*
Occupation of household head			
Farming	8 (61.5%)	14 (77.8%)	22 (70.97%)
Employed	1 (7.7%)	2 (11.1%)	3 (9.68%)
Others	4 (30.8%)	2 (11.1%)	6 (19.35%)
Total	*13 (100%)*	*18 (100%)*	*31 (100%)*
Education level of household head			
None	0 (0%)	2 (11.1%)	2 (6.45%)
Lower Primary	0 (0%)	2 (11.1%)	2 (6.45%)
Upper Primary	4 (30.8%)	6 (33.3%)	10 (32.26%)
Secondary	8 (61.5%)	7 (38.9%)	15 (48.39%)
Tertiary	1 (7.7%)	1 (5.6%)	2 (6.45%)
Total	*13 (100%)*	*18 (100%)*	*31 (100%)*

n=31. The study interviewed farmers who participated in the implementation of selected technologies. Values in the brackets are percentages of the respondents.

4.4.2 Farm characteristics

Table 4.16 shows the differences in population structure of Meru South and Gatanga. The age of the respondents ranged between 37 to 63 years in Meru South and 45 to 77 years in Gatanga. There were at least 9 adults per HH in Meru South and 6 in Gatanga. Farmer labour was majorly provided by males in Meru South and Gatanga (Table 4.16).

The farmers owned small pieces of land in both Meru South and Gatanga (Table 4.16). Average land size in Meru South was relatively large (4.29 acres) but land sizes in Gatanga barely measured more than 3 acres. More than half pieces of land were cultivated in both sites dominated by annual crops. The largest land size was found to be under inheritance in both sites followed by purchased while only small pieces of land were rented.

Table 4:16: Characteristics of the farms of those who implemented the selected technologies in Meru South and Gatanga

Farm characteristics	Site			
	Meru South		Gatanga	
	Mean	Std. Dev	Mean	Std. Dev
Age	49.69	13.431	60.61	16.212
Children	2.69	1.548	1.17	1.510
Adult males	2.69	2.097	2.33	1.500
Adult females	1.31	1.032	1.94	1.470
Adult residents	4.54	2.904	2.61	1.420
Dependants	2.46	2.876	1.06	1.630
HH males labour	1.38	1.193	1.44	0.920
HH females labour	0.92	0.494	1.00	0.490
Farm size (acres)	4.29	3.757	2.35	1.490
Land cultivated (acres)	2.82	3.433	1.68	1.300
Land under annual crops	2.41	3.576	1.01	1.160
Inherited land (acres)	2.50	1.770	2.28	2.730
Purchased land (acres)	1.68	2.290	1.08	2.030
Rented land (acres)	0.01	0.030	0.21	0.530
Number of livestock (head counts)	6.46	4.943	4.56	6.051
Estimate annual manure production (tons)	7.35	6.289	5.46	4.320
Farming experience (years in farming)	27.92	14.863	33.11	21.057

N=31 (sample size)

4.4.3 Knowledge of the selected integrated soil nutrients management technologies

The respondents were asked to name integrated soil nutrients management technologies implemented during the study. They were taken through a list of other soil fertility technologies and asked to state if they know the technologies. They were then asked to identify the technologies they have used in improving soil fertility and any other methods they use.

The result showed that all the farmers were able to accurately mention all the technologies they implemented per plot. This implied that the respondents actively participated in the technology selection and implementation. Regardless of tillage method, the use of goat manure, sole mineral fertilizer, integrating manure and mineral fertilizer and crop rotation were the most common soil fertility inputs used by all farmers in Meru South and Gatanga. The survey results revealed the growing popularity of integration of inputs as was demonstrated by a statement given by one of the respondents.

> *".....Most farmers rarely apply sole* mineral fertilizers *on their farms. We prefer to apply* goat *manure before planting and only add small amounts of* mineral fertilizer *during planting but not just use sole fertilizer. Apart from the high cost of the fertilizers, which we have to transport from agrovet shops situated far in Gatanga Town, we have noticed that soil fertility declines with time as a result of continuous use of the fertilizers."*

Minimum tillage, intercropping, terraces and *Tithonia diversifolia* were the other technologies the farmers identified. Though all the farmers revealed that they were aware of minimum tillage, not all of them practiced it. Out of the 18 and 13 farmers in Gatanga and Meru South, those who had practiced MT were ten (n=10) in each site. This could imply that farmers have high chances of adopting the technology among the respondents. Intercropping was also not used by all the respondents, nine (n=9) farmers in Gatanga sub-county and ten (n=10) in Meru South practiced it. Only one (n=1) respondent in Gatanga and four (n=4) in Meru South used terraces to control erosion and prevent loss of soil fertility. The minimal use of terraces both in Meru South and Gatanga could imply that farmers avoid its use since it takes large land space. Those who used *Tithonia diversifolia* were six (n=6) in Gatanga and only four (n=4) in Meru South. The respondents admitted that *Tithonia diversifolia* was readily available but for long had regarded it as fodder to feed their goats. One farmer from Meru South stated;

> *".....I never knew Maruru (local name for Tithonia diversifolia) could be used to improve soil fertility until you brought this training here. I always used it to feed my goats but having seen how it improved my yields in the last season, now I will be using it in my farms."*

4.4.4 Determinants of taking up selected integrated soil nutrients management technologies

From the study, goat manure and a combination of goat manure and mineral fertilizers were the common soil fertility improving methods the farmers used. The benefits related to effect of particular soil fertility input on soil, crop productivity, availability of the inputs and cost, and their residual effect. Majority of the respondents (n=10) and seven (n=7) in Meru South and Gatanga, respectively suggested that they obtained benefits through the impact of the soil fertility methods used on soil which included moisture conservation, addition of plant nutrients and control of soil erosion. Furthermore, increased crop production, fasten crop growth and control weeds and pests was mentioned by twelve (n=12) and eight (n=8) respondents in Gatanga and Meru South, respectively. Only two (n=2) and one (n=1) farmers in Gatanga and Meru South, said that they benefited from cheaper inputs while three (n=3) and two (n=2) reported that the advantage of their methods was that the inputs were readily available. The findings implied that farmers prefer technologies that would serve multiple purposes. They do not entirely rely on availability and one farmer from Gatanga Sub-county stated the cost of the technologies as;

> *".....I prefer soil fertility improvement method that not only improves my yield production but also that which will protect the quality of my farm. My choice is not so much affected by the availability of the inputs within the locality. For instance, I buy* goat *manure from other counties as far as from Laikipia when I run out of stock."*

The results also showed that all the respondents both from Meru South and Gatanga had used casual workers at least more than once and admitted that casual workers are readily available within the locality. However, the study revealed that the use of such workforce was subject to the kind of work to be done, farm size and the availability and size of family labour. Casual workers were mainly involved to work in cash crops such as in coffee and tea harvesting. Farmers owing less than an acre of land with roughly three families labour rarely sought to involve casual workers. These findings implied that farmers intended to reduce their operational costs by relying more on family labour and minimizing outsourced labour to high value crops and under relatively bigger pieces of land.

The majority of the farmers involved in the study from both sites did not consider non-farming sources of income to influence their choice of soil fertility improvement input. The majority (n=7) of the respondents had no sources of non-farming income. Remittances from relatives (n=4) and casual employment (n=4) were the common sources of non-farming income while pension (n=1) from retirement was the least popular among farmers in Gatanga while Meru South, two (n=2) farmers had no sources of income, while remittances from relatives (n=4) and income from casual work (n=7) were the main sources of non-farming income. Most of the respondents said that these sources of income are not reliable and insufficient to be used in farming activities thus they mainly rely on farming income. The majority (n=7, in Gatanga and n=10 in Meru South) of those who used non-farming income majorly used it to buy mineral fertilizers.

Majority of the farmers (n=16 and n=12, Gatanga and Meru South, respectively) believed that their experience in farming activities puts them in a better position to choose soil fertility inputs suitable for their farms. Moreover, they were able to assess soil fertility status of their farms and availability of organic inputs. Eleven (n=11) and two (n=2) of the farmers rated their farm soil fertility as “good” while seven (n=7) and eleven (n=11), in Gatanga and Meru South, respectively, rated their farm soil fertility status as “moderate”. The respondents admitted that they maintain or improve soil fertility by continual application of goat manure and control of soil erosion. The findings implied that soil fertility as a problem affecting agricultural production capacity of the farmers and that is why they invest in measures that maintain/or improve soil fertility.

4.4.5 Likelihood of future utilization of selected integrated soil nutrients management technologies

The respondents were asked whether they would continue practicing soil fertility improvement technologies that they implemented. The continuity of the technology use was assessed by involvement of other family members hence the respondents were asked if and how they involved other family members in the implementation of the project. They were also asked whether and how many other farmers within their environs visited their plots, learnt and implemented the same technologies.

The responses on the preferences of the tested tillage and soil nutrient management technologies by the farmers in Meru South and Gatanga are presented in Table 4.15. In Meru South, among those who implemented CON-Mf, only one farmer appraised it positively and that he will continue implementing the technology and would recommend it to other farmers. On the other hand, two farmers said they would continue practicing CON-RMf. Only one farmer would recommend it to other farmers. All the four farmers who implemented CON-RMfM said they would continue implementing the technology. Two of the four farmers said other farmers had visited their farms to learn about the technology. All the four farmers said they would recommend it to other farmers. All the farmers who implemented CON-RTiP said they would continue implementing the technology and would recommend it to other farmers.

Two farmers who implemented CON-RML said they would continue implementing the technology. Moreover, all the farmers who implemented CON-RTiM said they would continue implementing the technology. Three farmers said other farmers had visited their farms to learn about the technology while they all said they would recommend it to other farmers. Only one farmer agreed to continue implementing minimum tillage. All the four farmers, however, said that other farmers had visited their farms to learn. They stated that they would recommend the technology to other farmers. Among those who implemented MIN-Mf, only one farmer agreed to continue implementing the technology. Only one farmer who implemented MIN-RMf indicated a desire to continue practicing it though there was no attempt by other farmers to visit and learn about the technology. All the four farmers who implemented MIN-RMfM agreed to continue implementing it. Two of those farmers indicated that other farmers visited their farms to learn and that they would recommend it to other farmers. All those who implemented MIN-RTiP agreed to continue implementing it. All the four farmers were visited by other farmers to learn. They all said they would recommend the technology to other farmers.

In Gatanga, none of the farmers who implemented CON-Mf was willing to continue implementing it (Table 4.15). On the other hand, one farmer wished to continue practicing CON-RMf. Only one farmer agreed to recommend CON-RMf treatment to other farmers. Moreover, three farmers who implemented CON-RMfM said they would continue implementing the technology. Three farmers said other farmers had visited their farms to learn about the technology. They also said they would recommend it to other farmers. Additionally, all the farmers who implemented CON-RTiP said they would continue implementing it. They also said they would recommend it to other farmers. Of the farmers, two asserted that other farmers had visited their farms to learn. Also, two farmers who implemented CON-RML said they would continue implementing the technology. Three farmers said they would recommend it to other farmers. Besides, all the farmers who implemented CON-RTiM said they would continue implementing the technology while they all said they would recommend it to other farmers. In Gatanga only one farmer agreed to continue implementing minimum tillage. However, all the four farmers affirmed that other farmers in the area visited their trials to learn. Also, they stated that they would recommend the technology to other farmers. Only one farmer, who implemented MIN-RMf indicated a wish to continue practicing it. Three farmers who implemented MIN-RMfM said they would continue implementing it. Two farmers indicated that other farmers visited their farms to learn. They also said they would recommend it to other farmers. All of those who implemented MIN-RTiP agreed to continue implementing it. They also said other farmers visited their trials to learn. They said they would recommend the technology to other farmers. Lastly, three farmers agreed they continue to implement MIN-RTiM. They all affirmed that other farmers visited their fields to learn about MIN-RTiM.

Table 4:17: The number of farmers (out of 4 farmers per SNMT) who responded positively to questions pertaining to their likelihood to continue practising the SNMT they had implemented on their farms

Selected SNMT	**Would you continue implementing**		**Have other farmers from the neighbourhood learnt from your field**		**Would you recommend the technology to other farmers?**	
	Meru South	**Gatanga**	**Meru South**	**Gatanga**	**Meru South**	**Gatanga**
CON-Mf	1	0	0	0	1	0
CON-RMf	2	1	0	0	1	1
CON-RMfM	4	3	2	3	4	3
CON-RTiP	4	4	1	2	3	3
CON-RML	2	2	0	4	3	3
CON-RTiM	4	4	3	1	4	4
Minimum Tillage	1	1	1	1	1	1
MIN-Mf	1	0	0	0	1	0
MIN-RMf	1	1	0	0	1	1
MIN-RMfM	4	3	2	2	4	3
MIN-RTiP	4	4	3	2	4	4
MIN-RML	1	1	2	1	1	1
MIN-RTiM	4	3	1	3	4	3

Abbreviation: CON-Mf, minimum tillage + mineral fertilizer; CON-RMf, minimum tillage + crop residues + mineral fertilizer; CON-RMfM, minimum tillage + crop residues + mineral fertilizer + animal manure; CON-RML, minimum tillage + crop residues + animal manure + legume intercrop; CON-RTiM, minimum tillage + crop residue + *Tithonia diversifolia* + animal manure; CON-RTiP, minimum tillage + crop residues + *Tithonia diversifolia* + rock phosphate; MIN-Mf, minimum tillage + mineral fertilizer; MIN-RMf, minimum tillage + crop residues + mineral fertilizer; MIN-RMfM, minimum tillage + crop residues + mineral fertilizer + animal manure; MIN-RML, minimum tillage + crop residues + animal manure + legume intercrop; MIN-RTiM, minimum tillage + crop residue + *Tithonia diversifolia* + animal manure; MIN_RTiP, minimum tillage + crop residues + *Tithonia diversifolia* + rock phosphate.

4.4.6 Factors that potentially can limit the use of various soil fertility techniques

It was found that crop type affected the choice of soil fertility inputs used both in Meru South and Gatanga. The majority of the respondents combined mineral fertilizer with goat manure (n=24), sole goat manure (n=4) and sole mineral fertilizers (n=1) in cash crops. Commonly used inputs on food crops were mineral fertilizer (n=18), integration of goat manure and fertilizers (n=10) and sole goat manure (n=3). Mulching was mainly used in Irish potatoes. The farmers mostly used sole mineral fertilizers on food crops and rarely used it in bananas and avocadoes as it was cited that fertilizer reduces the quality of the produce. The need for faster crop maturity, quality of produce and residual effect of the inputs were the main determinant factors that influenced the use of a particular soil fertility inputs on different crops. For instance, where organic resources such as manure were scare, priority was given to cash crops at the expense of food crops since the farmers considered goat manure to having lasting effect on SF. Sole mineral fertilizers were used on food crops to fasten maturity before rainfall cessation. The farmers reported that for good quality produce to be sold in the markets, they combined little mineral fertilizer with lots of goat manure. The findings implied that farmers' choice of soil fertility inputs was influenced by the crop type that earns income for the family.

Farmers both in Meru South and Gatanga reported that integrated approaches are labour intensive (n=7), expensive and getting inputs to integrate is a problem (n=4). On the other hand it was reported that sole mineral fertilizers was expensive (n=18), availability of fake mineral fertilizers in the market, leads to crop scorching under rainfall shortages and deteriorates soil health (n=5) and leads to stunted growth at some stages of crop growth. It was also reported that intercropping leads to reduction of crop yield of one of the intercropped crops (n=8), makes farm operation difficult and acts as alternate host to pests and diseases (n=5). Goat manure and *Tithonia diversifolia* were noted to be bulky, labour intensive (n=10) and at times are short in supply (n=13). It was also revealed that goat manure causes soil crusting, harbours pests, delays seed germination and promotes weeds germination (n=4) and at times expensive while mulch took longer to decompose and release nutrients, requires proper management to avoid loss of nutrients. Furthermore, minimum tillage was said to be tiresome to implement (n=7), restricts root development, slows down farm operations (n=3), leads to bodily harm (n=2) and promotes weeds growth (n=6).

Chapter 5

5.0 DISCUSSIONS, CONCLUSION AND RECOMMENDATIONS

5.1 Discussions

5.1.1 Effect of treatments on selected soil parameters

Nutrients are vital in regulating root system architecture resulting in efficient nutrient uptake by plants (Shahzad and Amtmann 2017). The lowest amounts of N, P and K recorded under CON-C in Meru South, and Gatanga (Table 4.2 and 4.4) was probably because of the effect of deep ploughing and mining through crop harvesting. Deep tilling could have resulted in soil erosion or/and deep percolation of the nutrients beyond root zones. Maize stovers were harvested and not returned to the soil under CON-C as such could have led to N, P and K mining. These findings are in agreement with the results of the study conducted in Western India where K on the topsoil decreased both under reduced and conventional tillage systems (Singh *et al* 2018).

In Meru South, the observed increases in N under CON-Mf and MIN-Mf probably were because of the effect of mineral fertilizer. The increase in N under MIN-RML and MIN-RTiM could have been as a result of the effects of minimum tillage, legume intercrop (*Dolichos lablab*), *goat* manure and *Tithonia diversifolia*. Additionally, the increase in N under CON-RTiP could also be ascribed to *Tithonia diversifolia*. Similar results were obtained by other researchers. For instance, Smith *et al* (2016) found that N application rate reduced remarkably following legume intercrop in Malawi. *Dolichos lablab* reduced N and P uptake while improving their use efficiency in potato-Dolichos intercrop (Gitari *et al* 2018).

In Gatanga, the observed N increase under CON-Mf, MIN-Mf, and CON-RTiM could be because of the released N from the applied mineral fertilizer, *goat* manure and *Tithonia diversifolia*. Soil aggregation could have improved under minimum tillage resulting in the protection of N against microbial attacks. Zhang *et al* (2018) stated that conservation tillage improved soil macro-aggregates and could improve integrated soil fertility if combined with crop residue retention. On the other hand, the significant increments in P under MIN-RMF and CON-RMfM in Meru South and Gatanga could have been due to P from *goat* manure and mineral fertilizer while the released P could have been protected from erosion under MIN-RMf and MIN-Mf, respectively. The observed increase in K under MIN-RTiP in Meru South could have resulted as a result of K from *Tithonia diversifolia* and protected from erosion by crop residues and minimum tillage. Yang *et al* (2011) found that *goat* manure significantly improved N, P and K in Beijing while Adekiya and Agbede (2017) reported increased N and P, in Nigeria when poultry manure was incorporated in the soil. Additionally, combining *goat* manure with NPK mineral fertilizer annually increased P by 77 Kg ha^{-1} in China (Yang *et al* 2014). In the Central Highlands of Kenya, application of manure increased K (Serafim *et al* 2013).

5.1.2 Decomposability of goat manure and *Tithonia diversifolia*

The rapid rates of decomposition exhibited by goat manure and *Tithonia diversifolia* during the first 28 and 14 days of burying in Meru South and Gatanga, respectively (Fig. 4.3 and 4.4) probably occurred because of the priming and leaching effects. This finding is similar to the results of Fontaine *et al* (2003) who stated that the rapid decomposition rates observed was due to priming effect when fresh plant litters were added to the soil. Li *et al* (2012) concluded that leaching could have led to increased litter decomposition rates in the initial decomposition stages. However, decomposition rates of two litters in Meru South and Gatanga could have started to decline because of increased lignified components. Berg (2000) divided decomposition rate into two, early and late stages. In the early stages decomposition rate increases rapidly while in the later stages, the decomposition rate and mass loss reaches a limit value and starts to decline. Through pyrolysis process, Yuan *et al* (2017) demonstrated that goat manure underwent through three-stage reactions. The authors suggested that phase one was dominated by extractives and hemicellulose component reactions, phase two was characterized by lignin and cellulose while the last stages was dominated by lignin and mineral constituents. Another study using kinetic analysis method to observe decomposition of cattle manure revealed that conversion degrees reduced as more recalcitrant are formed (Chen *et al,* 2017). The higher decomposition rate recorded in *Tithonia diversifolia* than in goat manure in Meru

South and Gatanga could be because *Tithonia diversifolia* had more labile components thus decomposed faster than goat manure that could have contained more recalcitrant materials. Consequently, the speedy rate of decomposition rates expressed by goat manure and *Tithonia diversifolia* could have explained the rapid mass losses observed in the two litters in Meru South and Gatanga, 14 days after burying (Table 4.9). A study conducted by Valeem and Farooqui, (2009) suggested that leaching is the primary pathway of litter mass loss. Despite the initial higher amounts of N, P and K in *Tithonia diversifolia* than in goat manure, goat manure had higher remaining N, P and K than *Tithonia diversifolia* both in Meru South and Gatanga. This could be attributed to the slow rate of decomposition exhibited by goat manure relative to *Tithonia diversifolia.* Another study confirmed that litter type influences decomposition pattern and rate (Mazzilli *et al*, 2014). Goat manure lost minimal mass after 56 and 70 days probably because all the labile components had been decomposed and the remaining components were lignified thus slowing the decomposition rate.

5.1.3 Effect of treatments on maize above-ground yield

There was more grain yield in LR2016 than in SR2016 both in Meru South and Gatanga (Table 4.11) because rainfall and distribution were better in LR2016 than in SR2016 (Fig. 3.2). Other studies have confirmed the effect of rainfall amounts and distribution on seasonal maize yield variations (Kiboi *et al* 2017). The findings of this study concur with that of (Okeyo *et al* 2014) findings on an on-station experiment conducted in Meru South (Kigogo) where they observed higher maize yields when rainfall amounts were well distributed during important maize growth stages. A study conducted in Tanzania to assess the relationship between seasonal climatic factors and cereal yields found that cereal yields are affected by inter- and intra-seasonal changes in temperature and rainfall (Rowhani *et al* 2011). The higher maize above-ground yields during LR2016 could also be because of the initial inherent soil fertility. A study conducted in the study area confirmed that maize grain yield was higher during the first season of treatments implementation due to initial soil fertility (Adamtey *et al* 2016). The magnitude of maize yield depended on climatic and soil conditions in Żelazna (Rutkowska *et al* 2018).

The highest maize grain yield recorded under MIN-RMfM during LR2016 and MIN-RTiP during SR2016 in Meru South and Gatanga during LR2016, respectively are ascribed to the application of rock phosphate. Rock phosphate has a long-lasting residual effect in supplying P (Husnain *et al* 2014). We attributed the observed higher maize grain yields under MIN-RTiM, CON-RMfM, MIN-RML, CON-RTiM, MIN-RMf, MIN-RMfM, CON-RMf and MIN-Mf in Meru South during SR2016 and under CON-RMfM, CON-RTiP, CON-RTiM, MIN-RTiM and MIN-RMfM in Gatanga during LR2016 to the synergic effect of minimum tillage, crop residue management, *Tithonia diversifolia*, *goat* manure and rock phosphate. An on-station study conducted in the Central Highlands of Kenya revealed that application of N from mineral fertilizers enhanced maize yield and response to tillage method and residue retention by altering nitrogen nutrition index and crop growth rate (Kitonyo *et al* 2018). The increased yields under CON-RMf, CON-RMfM, CON-RTiP and CON-RTiM were probably as a result of good root development attributed to the synergetic effect of integrating soil fertility inputs. The roots could have explored deeper soil masses in search of soil moisture, a derived argument based on Cai *et al* who observed that sub-soiling improves root development and distribution, and increases nutrient accumulation (Cai *et al*, 2014). Other studies have also observed increased maize grain yield when minimum tillage, crop residue, *Tithonia diversifolia*, and rock phosphates are applied (Tao *et al* 2015).

The high stover yields observed under MIN-RMfM, CON-RMfM, CON-RTiM, CON-RMf, MIN-Mf, MIN-RMf and CON-RTiP during LR2016, and MIN-RTiP MIN-RMfM and MIN-RTiM during SR2016 in Meru South and MIN-RTiM, MIN-RMfM, MIN-RTiP, MIN-Mf, MIN-RMf, MIN-RML, CON-RML, CON-RMfM, CON-RTiM, CON-Mf, CON-RTiP, CON-RMf in Gatanga during LR2016 could be attributed to the effect applied soil fertility inputs and tillage. Studies have confirmed the effect of NPK fertilizer on stover yields (Bhattacharyya *et al* 2015). Application of N significantly increased maize stover yield in China (Liang *et al* 2015). *Tithonia diversifolia*, rock phosphate and *goat* manure, released plant available nutrients thus promoting rapid vegetative growth. Minimum tillage and crop residues could have conserved soil moisture and limited leaching of the released plant nutrients. Sime *et al* (2015) observed similar results, where minimum tillage and mulch were found to protect nutrient loss. Under conservation, tillage could also have improved root water extraction during soil water scarcity thus improving above-ground biomass. The crop failure experienced during SR2016 in Gatanga was due to low rainfall amounts and distribution. Though there was early rainfall onset (6th October), instances of dry spells occurred during critical maize vegetative and reproductive stages leading to total crop failure.

5.1.4 Likelihood of selected technologies uptake

The selected soil nutrient management technologies (Table 4.17) were preferred based on the characteristics of the technologies and farmers' traits. The respondents generally cited the ability of the technologies to improve soil fertility, crop yield, ease of implementation and availability of inputs as the technology traits, and availability of household labor, ability to hire labor and age as farmer characteristics that influenced their decision to continue practicing the chosen technologies. Similar results were obtained by Marenya and Barrett (2007), who revealed that technology uptake was affected by the availability of household labor. This finding is in agreement with the results of Mugwe *et al* (2009) who found that farmer's ability to hire labor was a positive factor in the adoption of integrated soil fertility management practices in the Central Highlands of Kenya. Mango *et al* (2017) suggested that farmer's age was vital in the uptake of soil, water and land conservation technologies in South Africa. The farmers are likely to take up the selected SNMTs because they participated in the technology implementation trials. A study conducted in the Ethiopian highlands concluded that genuine farmers' participation was essential to the adoption of soil and water conservation technologies (Mekuriaw *et al* 2018).

The preference of integrated nutrient management technologies in Meru South and Gatanga is associated with the observed increase in maize yield and improved soil fertility. Also, the preference might have been because inputs were readily available within their localities and technologies were easy to implement. A study conducted in Zimbabwe found that integrated soil nutrient technologies increased maize productivity in regions receiving low rainfall and with poor soils (Kafesu *et al* 2018). In our study sites, those who preferred approaches that integrated conventional tillage (CT) said that it was easy to implement and suitable in controlling weeds. On the other hand, those who supported the approach that integrated minimum tillage (MT) suggested that it was better in conserving soil moisture and controlling soil erosion thus improved maize yield. Ward *et al* stated that residue mulching and legume intercrop had replica effect on adoption of zero tillage in Malawi (Ward *et al* 2018). A study conducted in Western Cameroon found out that above 90 and 18.8% of farmers use minimum tillage and mineral fertilizers to improve soil fertility (Kome *et al* 2018). Another study conducted in Southern Africa revealed that farmers preferred nutrient-dense inputs such as mineral fertilizers, *goat* manure and compost in pieces of land that need minimum input applications (Mponela eta al. 2016). Nonetheless, the use of maize stover as soil surface management strategy was not much appreciated in both Meru South and Gatanga since farmers use the stovers as fodder. However, continued use of maize stover can be encouraged through farmer training as reported by Jaleta *et al* (2015) where they observed that more extension training on residue management in mixed crop-livestock systems increased the use of crop residues as soil fertility amendment in Ethiopia.

The farmers who participated in the implementation of the trials can act as an opinion leader or lead farmers thus; they can easily influence the decision making of the neighboring farmers. Based on a study conducted in Malawi, Holden *et al* showed that increased adoption of mulching, organic manure, and minimum tillage was as a result of lead farmers recommending to their followers (Holden *et al* 2018). Uptake of minimum tillage increased in Zambia when lead farmers adopted it (Grabowski *et al* 2014). Farmers who were not involved in the implementation of the trials but visited the trials were either attracted by their desire to learn about the technologies or just sheer curiosity and possibly, they may or may not take up the technologies. According to Wollni and Andersson (2014), adoption of SNMT can be enhanced through improved information availability within neighborhoods and when the adopting farmers believe that their actions are meeting the expectations of their neighbors.

5.2 Conclusions

- The study has shown that soil fertility inputs play an essential role in replenishing soil nutrients (N, P and K) thus improve crop productivity (maize) within a short period (two cropping seasons). Integrating soil nutrient management technologies increases maize yield (grain and stover) under on-farm conditions. Tillage types seemed not to have any specific positive effect on either soil nutrient content or maize yield.
- The study demonstrates that goat manure and Tithonia diversifolia decompose and release nutrients in different patterns.
- The findings also demonstrated that the likelihood of a farmer taking up an SNMT depends on the ability of the technology to improve soil fertility, crop yield, ease of its implementation, availability of inputs and labor, and farmer's age.

5.3 Recommendations

- In regard to integrated soil nutrients management technologies for improved soil fertility, integration of soil nutrients management technologies offers resource-poor smallholder farmers alternatives to choose from. The technologies involve inputs that are readily available within the farmers' localities. The study therefore recommends that farmers should be encouraged to use integrated approaches alternately to meet their economic needs without putting much pressure on one particular resource.
- Goat manure and *Tithonia diversifolia* provide alternative solution to soil degradation. Due to their differences in decomposition rates, the study recommends the use of *Tithonia diversifolia* for short-term soil fertility improvement because it has faster decomposition rate. Goat manure degrades relatively slowly hence would be suitable for medium and long-run soil fertility improvement strategy.
- In relation to integrated soil nutrients management technologies for improved maize yield, farmers need technologies that meet their immediate food production needs and long-run soil fertility build-up. The study recommends the use of the

selected integrated soil nutrients management technologies for improved maize grain and stover production.

- To increase probabilities of uptake of the selected integrated soil nutrients management technologies, women play an important role in agricultural production. The study recommends more women sensitization activities in Meru South and Gatanga on the use of integrated soil nutrients management technologies.

5.3.1 Area for further research

Due to the complexity and confounding effects of combining tillage methods, mineral fertilizers and residue retention, there is a need to carry out further research, probably using omission trial approach, to tease out individual parameter effects on crop performance.

REFERENCES

Abdi El Hameed, A. H., Eweda, W. E., Abou-Taleb, K. A. A. and Mira, H. I. (2015). Biosorption of uranium and heavy metals using some local fungi isolated from phosphatic fertilizers. *Annals of Agricultural Sciences*, 60, 345–351.

Abdullah, A. S. (2014). Minimum tillage and residue management increase soil water content, soil organic matter and canola seed yield and seed oil content in the semiarid areas of Northern Iraq. *Soil and Tillage Research*, 150–155.

Abiven, S. and Chenu, C. (2009). The effects of organic inputs over time on soil aggregate stability - A literature analysis. *Soil Biology and Biochemistry*, 41, 1–12.

Adamtey, N., Musyoka, M.W., Zundel, C., Cobo, J.G., Karanja, E., Fiaboe, K. K. M., Muriuki, A., Mucheru-Muna, M., Vanlauwe, B., Berset, E., Messmer, M.M., Gattinger, A., Bhullar, G.S., Cadisch, G., Fliessbach, A. and Foster, D. (2016). Productivity, profitability and partial nutrient balance in maize-based conventional and organic farming systems in Kenya. *Agriculture, Ecosystems and Environment*, 235, 61–79.

Adekiya, A. O., Agbede, T. M., Aboyeji, C. M., Dunsin, O. and Ugbe, J. O. (2018). Green manures and NPK fertilizer effects on soil properties, growth, yield, mineraland vitamin C composition of okra (Abelmoschus esculentus (L.) Moench). *Journal of the Saudi Society of Agricultural Sciences (in press).*

Adekiya, A. O. and Agbede, T. M. (2017). Effect of methods and time of poultry manure application on soil and leaf nutrient concentrations, growth and fruit yield of tomato (*Lycopersicon esculentum Mill*). *Journal of the Saudi Society of Agricultural Sciences*, 16, 383-388

Ademiluyi, B. and Omotoso, S. (2007). Comparative evaluation of *Tithonia diversifolia* and NPK fertilizer for soil improvement in maize (*Zea mays*) production in Ado Ekiti, Southwestern Nigeria. *American-Eurasian Journal*, 1, 32–36.

Adesina, A. A., Mbila, D., Blaise, G. and Endamana, D. (2008). Econometric analysis of the determinants of up-take of alley farming by farmers in the forest zone of southwest Cameroon. *Agriculture, Ecosystems and Environment*, 80, 255–265.

Adusumilli, N. and Wang, H. (2017). Analysis of Soil Management and Water Conservation Practices adoption among Crop and Pasture Farmers in Humid-South of the United States. *International Soil and Water Conservation Research*, 6, 79-86.

Ahmad, W., Shah, Z., Jamal, M. and Ali, K. (2014). Recovery of organic fertility in degraded soil through fertilization and crop rotation. *Journal of the Saudi Society of* Agricultural *Sciences*, 13, 92–99.

Akhir, N. I. M., Kusin, F. M., Mohamat-Yusuff, F., Awang, M. and Ash'aari, Z. H. (2015). Impact of Nitrogen Fertilizer Application on Nitrous Oxide Emission in Oil Palm Plantation. *Procedia Environmental Sciences, 30, 315–319*.

Albert Bandura (Ed.). (1999). Social cognitive theory : An agentic Albert Bandura. Stanford University, USA: Blackwell Publishers Ltd with the Asian Association of Social Psychology and the Japanese Group Dynamics Association 1999.

Albert Bandura. (1995). Self-efficacy in Changing Socities. (A. Bandura, Ed.). The Pitt Building, Trumpington Street, Cambridge, United Kingdom: Cambridge University Press.

Amsalu, A. and Graaff, J. De. (2006). Determinants of up-take and continued use of stone terraces for soil and water conservation in an Ethiopian highland watershed. *Ecological Economics*, 1, 86-94.

Andersen, M. N. (2016). Decomposition processes under Bt (*Bacillus thuringiensis*) maize : Results of a multi-site experiment Decomposition processes under Bt (*Bacillus thuringiensis*) maize. *Soil Biology and Biochemistry*, 38, 195–199.

Ashworth A. J., DeBruyn J.M., Allen F.L. and Radosevich M., O. P. (2017). Microbial community structure is affected by cropping sequences and poultry litter under long-term no-tillage. *Soil Biology and Biochemistry*, 114, 210–219.

Ayoola O.T, (2015). Complementary Organic and Mineral fertilizer Application : Influence on Growth and Yield of Cassava, maize, melon Intercrop with a Relayed Cowpea. *Australian Journal of Basic and Applied Sciences*, 1,187–191.

Babana, A.H., Kassogué, A., Dicko, A.H., Maîga, K., Samaké, F., Traoré, D., Fané, R. and Faradji, F.A. (2016). Development of a biological phosphate fertilizer to improve wheat (T*riticum aestivum L*.) production in Mali. *Procedia Engeneering*, 138, 319–324.

Barrett P. M. and Barrett C. B. (2007). Household-level determinants of adoption of improved natural resources management practices among smallholder farmers in Western. *Food Policy*, 1, 1–40.

Behera, U. K. and Sharma, A. R. (2011). Effect of conservation tillage on performance of greengram–mustard–cowpea cropping system. *Journal of Soil and Water Conservation*, 10, 233 – 236.

Berg B. and McClaugherty C (2013). Plant litter: decomposition, humus formation and carbon sequestration. Springer-Verlag, Berlin, Heidelberg, 3rd ed., 315.

Berg, B. and Matzner, E. (2016). Effect of N deposition on decomposition of plant litter and soil organic matter in forest systems. *Environmental Reviews*, 5, 1–25.

Berger, T. W., Duboc, O., Djukic, I., Tatzber, M., Gerzabek, M. H. and Zehetner, F. (2015). Decomposition of beech (*Fagus sylvatica*) and pine (*Pinus nigra*) litter along an Alpine elevation gradient : Decay and nutrient release. *Geoderma*, 251, 92–104.

Bewket, W. (2007). Soil and water conservation intervention with conventional technologies in northwestern highlands of Ethiopia , Acceptance and up-take by farmers. *Land Use Policy*, 24, 404–416.

Bhan, Suraj, and Behera, U. K. (2014). Conservation agriculture in India–problems, prospects and policy issues. *International Soil and Water Conservation Research*, 2, 1–12.

Bhattacharyya, P., Nayak, A.K., Shahid, M., Tripathi, R., Mohanty, S., Kumar, A. and Dash, P.K. (2015). Effects of 42-year long-term fertilizer management on soil phosphorus availability, fractionation, adsorption–desorption isotherm and plant uptake in flooded tropical rice. *Crop Journal*, 3, 387–395.

Bissett, A., Richardson, A. E., Baker, G., Kirkegaard, J. and Thrall, P. H. (2013). Bacterial community response to tillage and nutrient additions in a long-term wheat cropping experiment. *Soil Biology and Biochemistry*, 58, 281–292.

Bjorn, B., Berg , B. (2000). Litter decomposition and organic matter turnover in northern forest soils. *Forest Ecology and Management*, 133, 13–22.

Blanchet, G., Gavazov, K., Bragazza, L. and Sinaj, S. (2016). Responses of soil properties and crop yields to different mineraland organic amendments in a Swiss conventional farming system. *Agriculture, Ecosystems and Environment*, 230, 116–126.

Blonska, Ewa and Lasota, J. (2017). Soil Organic Matter Accumulation and Carbon Fractions along a Moisture Gradient of Forest Soils. *Forest Soils*, 8, 448–460.

Bonanomi G, Incerti G, Antignani V, Capodilupo M and Mazzoleni S (2010). Decomposition and nutrient dynamics in mixed litter of Mediterranean species. *Plant Soil*, 331, 481–496

Bonanomi G, Incerti G, Giannino F, Mingo A, Lanzotti V. and Mazzoleni S (2013) Litter quality assessed by solid state ^{13}C NMR spectroscopy predicts decay rate better than C/N and lignin/N ratios. *Soil Biology and Biochemistry* 56, 40–48.

Bradford MA, Berg B, Maynard D. S., Wieder W. R. and Wood SA (2016). Understanding the dominant controls on litter decomposition. *Journal of Ecology* 104,229–238.

Brandsæter, L. O., Mangerud, K., Helgheim, M. and Berge, T. W. (2017). Control of perennial weeds in spring cereals through stubble cultivation and mouldboard ploughing during autumn or spring. *Crop Protection*, 98, 16–23.

Busari, M. a., Kukal, S. S., Kaur, A., Bhatt, R., and Dulazi, A. A. (2015). Conservation tillage impacts on soil, crop and the environment. *International Soil and Water Conservation Research*, 3, 1–11.

Cadisch, G. (2001). Organic inputs for soil fertility management in tropical agro-ecosystems : application of an organic resource database. *Agriculture Ecosystems and Environment,* 83, 26–42.

Cai Z. J., Wang B. R., Xu M. G., Zhang H. M, He X. H, Zhang L. and Gao S D. (2015). Intensified soil acidification from chemical N fertilization and prevention by manure in an 18-year field experiment in the red soil of southern China. *Journal of Soils and Sediments*, 15, 260–270.

Cai, H., Ma, W., Zhang, X., Ping, J., Yan, X., Liu, J. and Ren, J. (2014). Effect of subsoil tillage depth on nutrient accumulation, root distribution, and grain yield in spring maize. *Crop Journal*, 2, 297–307.

Cao, X., Long, H., Lei, Q., Liu, J., Zhang, J., Zhang, W. and Wu, S. (2016). Spatio-temporal variations in organic carbon density and carbon sequestration potential in the topsoil of Hebei Province, China. *Journal of Integrative Agriculture*, 15, 2627–2638.

Carey, J. C., Moran, S. B. and Kelly, R. P. (2017). The Declining Role of Organic Matter in New England Salt Marshes. *Estuaries and Coasts*, 40, 626–639.

Castellanos-Navarrete, A., Tittonell, P., Rufino, M. C. and Giller, K. E. (2014). Feeding, crop residue and manure management for integrated soil fertility management - A case study from Kenya. *Agricultural Systems*, 134, 24–35.

Chen, J.-H. (2006). the Combined use of chemical and organic fertilizers and/or biofertilizer for crop growth and soil fertility. in international workshop on sustained management of the soil-rhizosphere *System for Efficient Crop Production and Fertilizer Use,* 10, 1–11.

Chetan, C., Rusu, T., Chetan, F., and Simon, A. (2016). Influence of Soil Tillage Systems and Weed Control Treatments on Root Nodules, Production and Qualitative Indicators of Soybean. *Procedia Technology*, 22, 457–464.

Chivenge, P., Vanlauwe, B., Gentile, R., Wangechi, H., Mugendi, D., van Kessel, C. and Six, J. (2009). Organic and mineralinput management to enhance crop productivity in central Kenya. *Agronomy Journal*, 101, 1266–1275.

Choudhury, S.G., Srivastava, S., Singh, R., Chaudhari, S. K., Sharma, D. K., Singh, S. K. and Sarkar, D. (2014). Tillage and residue management effects on soil aggregation, organic carbon dynamics and yield attribute in rice-wheat cropping system under reclaimed sodic soil. *Soil and Tillage Research*, 136, 76–83.

Cleveland, C. C., Reed, S. C. and Townsend, A. R. (2006). Nutrient Regulation of Organic Matter Decomposition in a Tropical Rain Forest. *Ecology*, 87, 492–503.

Coq S, Souquet JM, Meudec E, Cheynier V. and Hättenschwiler S. (2010). Interspecific variation in leaf litter tannins drives decomposition in a tropical rain forest of French Guiana. *Ecology*, 91, 2080–2091.

Cornwell WK, Cornelissen J. H. C., Amatangelo K. et al. (2008). Plant species traits are the predominant control on litter decomposition rates within biomes worldwide. *Ecology Letters*, 11:1065–1071.

Cotrufo, M. F. (2016). The Microbial Efficiency-Matrix Stabilization (MEMS) framework integrates plant litter decomposition with soil organic matter stabilization : Do labile plant inputs form stable soil. The microbial efficiency-matrix stabilization (MEMS) framework. *Global Change Biology*, 19, 988–995.

Craswell, E. and Lefroy, R. (2001). The role and function of organic matter in tropical soils. *Nutrient Cycling in Agroecosystems*, 61, 7–18.

Diacono M. and Montemurro F. (2010). Long-term effects of organic amendments on soil fertility. *Agronomy for Sustainable Development*, 30, 401–422.

Dikgwatlhe, S.B., Chen, Z. Du, Lal, R., Zhang, H.L. and Chen, F. (2014). Changes in soil organic carbon and nitrogen as affected by tillage and residue management under wheat-maize cropping system in the North China Plain. *Soil and Tillage Research*, 144, 110–118.

Ding X L, Liang C, Zhang B, Yuan Y. R and Han X. Z. (2015). Higher rates of manure application lead to greater accumulation of both fungal and bacterial residues in macroaggregates of a clay soil. *Soil Biology and Biochemistry*, 84, 137–146.

Doran, J. W. (1987). *Microbial* biomass and mineralizable nitrogen distribution into-tillage and plowed soils. *Biology and Fertility of Soils*, 5, 68–75.

Dornbush, M. E., Isenhart, T. M. and Raich, J. W. (2002). Quantifying Fine-Root *Decomposition* : an alternative to buried litterbags. *Forestry Publications*, 83, 2985–2990.

Du, Z., Ren, T., Hu, C. and Zhang, Q. (2015). Transition from intensive tillage to no-till enhances *carbon* sequestration in microaggregates of surface soil in the North China Plain. *Soil and Tillage Research*, 146, 26–31.

Endale, D. M., Potter, T. L., Strickland, T. C. and Bosch, D. D. (2017). Sediment-bound total organic carbon and total organic nitrogen losses from conventional and strip tillage cropping systems. *Soil and Tillage Research*, 171, 25–34.

Faissal, A., Ouazzani, N., Parrado, J. R., Dary, M. and Manyani, H. (2017). Impact of fertilization by natural manure on the microbial quality of soil : Molecular approach. *Saudi Journal of Biological Sciences*, 24, 1437–1443.

Farrell, M., Prendergast-Miller, M., Jones, D. L., Hill, P. W. and Condron, L. M. (2014). Soil microbial organic nitrogen uptake is regulated by carbon availability. *Soil Biology and Biochemistry*, 77, 261–267.

Festinger, L. (1957). A theory of cognitive dissonance, Evanston, IL: Row and Peterson.

Fontaine, S., Mariotti, A. and Abbadie, L. (2003). The priming effect of organic matter: A question of microbial competition? *Soil Biology and Biochemistry*, 35, 837–843.

Serah W.K. Muchai, Monicah W.M. Muna, Jane N. M. And Daniel N. M. (2014). Client focused extension approach for disseminating soil fertility management in Central Kenya. *International Journal of Agricultural Extension*, 02, 129–136.

Ghimire, R., Lamichhane, S., Acharya, B. S., Bista, P. and Sainju, U. M. (2017). Tillage , crop residue , and nutrient management effects on soil organic carbon in rice-based cropping systems : A review. *Journal of Integrative Agriculture*, 16, 1–15.

Gitari, Harun I, Nancy N. K., Charles K. K., Solomon K., Kalpana S. and Elmar S. (2018). Nitrogen and phosphorous uptake by potato (*Solanum tuberosum L*) and their use efficiency under potato-legume intercropping systems." *Field Crops Research*, 222: 78–84.

Godfray H. and Garnett T. (2014). Food security and sustainable intensification. *Philosophical Transactions of the Royal Society*, 369, 101–120.

Grabowski, P. P., Haggblade, S., Kabwe, S. and Tembo, G. (2014). Minimum tillage adoption among commercial smallholder cotton farmers in Zambia, 2002 to 2011. *Agricultural Systems*, 131, 34–44.

Güereña, D. T., Kimetu, J., Riha, S., Neufeldt, H. and Lehmann, J. (2016). Maize productivity dynamics in response to mineral nutrient additions and legacy organic soil inputs of contrasting quality. *Field Crops Research*, 188, 113–120.

Güereña, D.T., Kimetu, J., Riha, S., Neufeldt, H. and Lehmann, J. (2016). Maize productivity dynamics in response to mineral nutrient additions and legacy organic soil inputs of contrasting quality. *Field Crops Research*, 188, 113–120.

Guimarães, D. V., Gonzaga, M. I. S., da Silva, T. O., da Silva, T. L., da Silva Dias, N. and Matias, M. I. S. (*2013*). Soil organic matter pools and carbon fractions in soil under different land uses. *Soil and Tillage Research*, 126, 177–182.

Haider, H., Smale, M. and Theriault, V. (2017). Intensification and intrahousehold decisions: Fertilizer adoption in Burkina Faso. *World Development*, 105, 310-320.

Hamadoun, A., Kassogué, A. and Hamadoun, A. (2016). Development of a biological phosphate fertilizer to improve wheat (*Triticum aestivum L*) production in Mali. *Procedia Engineering*, 138, 319–324.

Hättenschwiler S, Coq S, Barantal S. and Handa I. T. (2011). Leaf traits and decomposition in tropical rainforests: revisiting some commonly held views and towards a new hypothesis. *New Phytology*, 189, 950–965.

Hellin, J., Erenstein, O., Beuchelt, T., Camacho, C. and Flores, D. (2013). Maize stover use and sustainable crop production in mixed crop-livestock systems in Mexico. *Field Crops Research*, 153, 12–21.

Hishe, S., Lyimo, J. and Bewket, W. (2017). Soil and water conservation effects on soil properties in the Middle Silluh Valley, northern Ethiopia. *International Soil and Water Conservation Research*, 5, 231–240.

Holden, S. T., Fisher, M., Katengeza, S.P. and Thierfelder, C. (2018). Can lead farmers reveal the adoption potential of conservation agriculture? The case of Malawi. *Land use policy*, 76, 113–123.

Hossain, A. S. M. and Crouch, B. R. (1992). Patterns and determinants of up-take of farm practices: Some evidence from Bangladesh. *Agricultural Systems*, 38, 1–15.

Hossain, B., Rahman, M. and Chandra, J. (2017). Carbon mineralization and carbon dioxide emission from organic matter added soil under different temperature regimes. *International Journal of Recycling of Organic Waste in Agriculture*, 6, 311–319.

Hossain, M. F., Chen, W. and Zhang, Y. (2015). Bulk density of mineraland organic soils in the Canada's arctic and sub-arctic. *Information Processing in Agriculture*, 2, 183–190.

Husnain, Rochayati, S., Sutriadi, T., Nassir, A. and Sarwani, M. (2014). Improvement of soil fertility and crop production through direct application of phosphate rock on Maize in Indonesia. *Procedia Engineering*, 83, 336–343.

Husnain, Rochayati, S., Sutriadi, T., Nassir, A. and Sarwani, M. (2014). Improvement of soil fertility and crop production through direct application of phosphate rock on Maize in Indonesia. *Procedia Engineering*, 83, 336–343.

IUSS Working Group WRB. (2014). World reference base for soil resources. International soil classification system for naming soils and creating legends for soil maps. *World Soil Resources Reports* No. 106, 45-72.

Jaetzold, R., *Schmidt*, H., Hornet, Z.B. and Shisanya, C.A. (2007). Farm Management Handbook of Kenya. Natural Conditions and Farm Information. 2nd Edition. Vol.11/ C. Eastern Province. Ministry of Agriculture/GTZ, Nairobi, Kenya.

Jaetzold, R., Schmidt, H., Hornet, Z.B. Shisanya, C.A. 2007. Farm management handbook of Kenya. natural conditions and farm information. Vol.11/ C of Eastern Province Ministry of Agriculture/GTZ. 2nd Ed. Nairobi, Kenya.

Jaleta, M., Kassie, M. and Erenstein, O. (2015). Determinants of maize stover utilization as feed, fuel and soil amendment in mixed crop-livestock systems, Ethiopia. *Agricultural Systems*, 134, 17–23.

Jama, B., Palm, C. A., Buresh, R. J. and Niang, A. (2000). *Tithonia diversifolia* as a green manure for soil fertility improvement in western Kenya : A review. *Agroforestry Systems*, 49, 201–221.

Jayne, T. S. and Muyanga, M. (2012). Land constraints in Kenya's densely populated rural areas: Implications for food policy and institutional reform. *Food Security*, 4, 399–421.

Ji, B., Zhao, Y., Mu, X., Liu, K. and Li, C. (2013). Effects of tillage on soil physical properties *and* root growth of maize in loam and clay in central China. *Plant, Soil, and Environment*, 59, 295–302.

Jones, D. L., Magthab, E. A., Gleeson, D. B., Hill, P. W., Sánchez-Rodríguez, A. R., Roberts, P. And Murphy, D. V. (2018). Microbial competition for nitrogen and carbon is as intense in the subsoil as in the topsoil. *Soil Biology and Biochemistry*, 117, 72–82.

Kafesu, N., Chikowo, R., Mazarura, U., Gwenzi, W., Snapp, S. 2018. Comparative fertilization effects on maize productivity under conservation and conventional tillage on sandy soils in a smallholder cropping system in Zimbabwe. *Field Crops Research*, 218, 106–114.

Kenya National *Bureau* of Statistics (KNBS) Report. (2013). Statistical Abstract, 1-320

Kessler, A., Posthumus, H. and Tenge, A. (2008). Factors influencing up-take and continued use of long-term soil and water conservation measures in five developing countries. *Applied Geography*, 28, 271–280.

Kiboi, M.N., Ngetich, K.F., Diels, J., Mucheru-Muna, M., Mugwe, J., Mugendi, D.N. 2017. Minimum tillage, tied ridging and mulching for better maize yield and yield stability in the Central Highlands of Kenya. *Soil and Tillage Research*, 170, 157–166.

Kitonyo, O. M., Sadras, V. O., Zhou, Y. and Denton, M. D. (2018). Nitrogen fertilization modifies maize yield response to tillage and stubble in a sub-humid tropical environment. *Soil and Tillage Research*, 223, 113–124.

Kome, G. K., Enang, R. K., Palmer, B. and Yerima, K. (2018). Knowledge and management of soil fertility by farmers in Western Cameroon. *Geoderma Regional*, 2, 48–60.

Krauss, M., Ruser, R., Müller, T., Hansen, S., Mäder, P. and Gattinger, A. (2017). Impact of reduced tillage on greenhouse gas emissions and soil carbon stocks in an organic grass-clover ley - winter wheat cropping sequence. *Agriculture, Ecosystems and Environment*, 239, 324–333.

Kuzucu, M. and Dökmen, F. (2015). The effects of tillage on soil water content in dry areas. *Agriculture and Agricultural Science Procedia*, 4, 126–132.

Kuzyakov, Y. (2010). Priming effects: Interactions between living and dead organic matter. *Soil Biology and Biochemistry*, 42, 1363–1371.

Lal, R. (2007). World soils and global issues. *Soil and Tillage Research*, 97, 1–4.

Laudicina, V. A., Novara, A., Barbera, V., Egli, M. and Badalucco, L. (2015). Long-term tillage and cropping system effects on chemical and biochemical characteristics of soil organic matter in a mediterranean semiarid environment. *Land Degradation and Development*, 26, 45–53.

Li, H., Feng, W. ting, HE, X. hua, Zhu, P., Gao, H. jun, Sun, N., and Xu, M. (2017). Chemical fertilizers could be completely replaced by manure to maintain high maize yield and soil organic carbon (SOC) when SOC reaches a threshold in the Northeast China Plain. *Journal of Integrative Agriculture*, 16, 937–946.

Li, Z., Nie, X., Chang, X., Liu, L. and Sun, L. (2017. Characteristics of soil and organic carbon loss induced by water erosion on the Loess plateau in China. *Soil and Tillage Research,* 171 25–34.

Liang, M., Wang, G., Liang, W., Shi, P., Dang. J., Sui, P. And Hu, C. (2015). Yield and quality of maize stover : Variation among cultivars and effects of N fertilization. *Journal of Integrative Agriculture*, 14, 1581–1587.

Lipiec, J., Kus, J., Slowinska-Jurkiewicz, A. and Nosalewicz, A. (2006). Soil porosity and water infiltration as influenced by tillage methods. *Soil and Tillage Research*, 89, 210–220.

Liu, P., Wang, Q., Bai, J., Gao, H., Huang, L. and Xiao, R. (2010). Decomposition and return of C and N of plant litters of Phragmites australis and Suaeda salsa in typical wetlands of the Yellow River. *Procedia Environmental Sciences*, 2, 1717–1726.

Lundy, M. E., Pittelkow, C. M., Linquist, B. A., Liang, X., van Groenigen, K. J., Lee, J. and van Kessel, C. (2015). Nitrogen fertilization reduces yield declines following no-till adoption. *Field Crops Research*, 183, 204–210.

Lvaro-Fuentes, J., Arre, J. L., Gracia, R. and Lopez, M. V. (2008). Tillage and cropping intensification effects on soil aggregation: Temporal dynamics and controlling factors under semiarid conditions. *Geoderma*, 145, 390–396.

Magnone, D., Bouwman, A. F., Van Der Zee, S. E. A. T. M., Sattari, S. Z., Beusen, A. H. W. and Niasar, V. J. (2017). Efficiency of phosphorus resource use in Africa as defined by soil chemistry and the impact on crop production. *Energy Procedia*, 123, 97–104.

Mairura, F. S., Mugendi, D. N., Mwanje, J. I., Ramisch, J. J., Mbugua, P. K. and Chianu, J. N. (2008). Scientific evaluation of smallholder land use knowledge in Central Kenya. *Land Degradation and Development*, 90, 77–90.

Mango, N., Makate, C., Tamene, L., Mponela, P. and Ndengu, G. (2017). Awareness and adoption of land, soil and water conservation practices in the Chinyanja Triangle, Southern Africa. *International Soil and Water Conservation Research*, 5, 122–129.

Marenya, P. P. and Barrett, C. B. (2007). Household-level determinants of adoption of improved natural resources management practices among smallholder farmers in western Kenya. *Food Policy*, 32, 515–536.

Marles, R. J. (2017). Mineral nutrient composition of vegetables, fruits and grains: The context of reports of apparent historical declines. *Journal of Food Composition and Analysis*, 56, 93–103.

Meena, J. R., Behera, U. K., Chakraborty, D. and Sharma, A. R. (2015). Tillage and residue management effect on soil properties, crop performance and energy relations in greengram (*Vigna radiata* L.) under maize-based cropping systems. *International Soil and Water Conservation Research*, 3, 261–272.

Mekuriaw, A., Heinimann, A., Zeleke, G. and Hurni, H. (2018). Factors influencing the adoption of physical soil and water conservation practices in the Ethiopian highlands. *International Soil and Water Conservation Research*, 6, 23–30.

Mogaka, V., Ehrensperger, A., Iiyama, M., Birtel, M., Heim, E. and Gmuender, S. (2014). Understanding the underlying mechanisms of recent Jatropha curcas L. adoption by smallholders in Kenya: A rural livelihood assessment in Bondo, Kibwezi, and Kwale districts. *Energy for Sustainable Development*, 18, 9–15.

Mohammadshirazi, F., Mclaughlin, R. A., Heitman, J. L. and Brown, V. K. (2017). A multi-year study of tillage and amendment effects on compacted soils. *Journal of Environmental Management*, 203, 533–541.

Mohd Kusin, F., Izzati, M., Akhir, N., Mahamat-Yusuff, F. and Auang, M. (2015). The impact of nitrogen fertilizer use on greenhouse gas emissions in an oil palm plantation associated with land use change. *Procedia Environmental Sciences*, 28, 243–250.

Moser, C. M. and Barrett, C. B. (2003). The disappointing up-take dynamics of a yield-increasing, low external-input technology: The case of SRI in Madagascar. *Agricultural Systems*, 76, 1085–1100.

Mponela, P., Tamene, L., Ndengu, G., Magreta, R., Kihara, J. and Mango, N. (2016). Determinants of integrated soil fertility management technologies adoption by smallholder farmers in the Chinyanja Triangle of Southern Africa. *Land Use Policy*, 59, 38–48.

Mrabet, R., Saber, N., El-Brahli, A., Lahlou, S. and Bessam, F. (2000). Total, particulate organic matter and structural stability of a Calcixeroll soil under different wheat rotations and tillage systems in a semiarid area of Morocco. *Soil and Tillage Research*, 57, 225–235.

Mucheru-Muna, M., Mugendi, D., Kung'u, J., Mugwe, J. and Bationo, A. (2007). Effects of organic and mineral fertilizer inputs on maize yield and soil chemical properties in a maize cropping system in Meru South District, Kenya. *Agroforestry Systems*, 69, 189–197.

Mucheru-Muna, M., Pypers, P., Mugendi, D., Kung'u, J., Mugwe, J., Merckx, R. and Vanlauwe, B. (2010). A staggered maize-legume intercrop arrangement robustly increases crop yields and economic returns in the highlands of Central Kenya. *Field Crops Research*, 115, 132–139.

Mugwe, J., Mugendi, D. and Kungu, J. (2007). Effect of plant biomass, manure and mineral fertilizer on maize yield in the Central Highlands of Kenya. A*frican Crop* Science *Journal* 15, 111–126.

Mugwe, J., Mugendi, D., Mucheru-Muna, M., Odee, D., and Mairura, F. (2009). Effect of selected organic materials and mineral fertilizer on the soil fertility of a Humic Nitisol in the central highlands of Kenya. *Soil Use and Management*, 25, 434–440.

Mugwe, J., Mugendi, D., Odee, D. and Otieno, J. (2007). Evaluation of the potential of using nitrogen fixing legumes in smallholder farms of Meru South District, Kenya. In Advances in Integrated Soil Fertility Management in Sub-Saharan Africa: *Challenges and Opportunities*, p. 503-510.

Munyahali, W., Pypers, P., Swennen, R., Walangululu, J., Vanlauwe, B. and Merckx, R. (2017). Responses of cassava growth and yield to leaf harvesting frequency and NPK fertilizer in South Kivu, Democratic Republic of Congo. *Field Crops Research*, 214, 194–201.

Nabel, M., Temperton, V. M., Poorter, H., Lücke, A. and Jablonowski, N. D. (2016). Energizing marginal soils - The establishment of the energy crop Sida hermaphrodita as dependent on digestate fertilization, NPK, and legume intercropping. *Biomass and Bioenergy*, 87, 9–16.

Nabel, M., Temperton, V. M., Poorter, H., Lücke, A. and Jablonowski, N. D. (2016). Energizing marginal soils-The establishment of the energy crop *Sida hermaphrodita* as dependent on digestate fertilization, NPK, and legume intercropping. *Biomass and Bioenergy*, 87, 9–16.

Nachimuthu, G. and Hulugalle, N. (2016). On-farm gains and losses of soil organic carbon in terrestrial hydrological pathways: A review of empirical research. *International Soil and Water Conservation Research*, 4, 245–259.

Naijia, G. U. O., Xuezheng, S. H. I., Yongcun, Z., Shengxiang, X. U., Meiyan, W. and Ganlin, Z. (2017). Environmental and anthropogenic factors driving changes in paddy soil organic matter : A case study in the middle and lower Yangtze River Plain of China. *Pedosphere*, 27, 926–937.

Nascente, A. S., Li, Y. C. and Crusciol, C. A. C. (2013). Cover crops and no-till effects on physical fractions of soil organic matter. *Soil and Tillage Research*, 130, 52–57.

Neshev, N. and Manolov, I. (2015). Content and uptake of nutrients with plant biomass of potatoes depending on potassium fertilization. *Italian Oral Surgery,* 63–66.

Ngetich F. K, Shisanya C a, Mugwe J, Mucheru-muna M and Mugendi D. (2012). The Potential of Organic and MineralNutrient Sources in Sub-Saharan African Crop Farming Systems. Soil Fertility Improvement and Integrated Nutrient Management - *A Global Prospective*. 2012, 135–56.

Ngetich, K. F. (2012). Enhancing farmers' agricultural productivity through improved field management practices in the Central Highlands of Kenya. (*Thesis*).

Ngetich, K. F., Mucheru-muna, M., Mugwe, J. N., Shisanya, C. A., Diels, J. and Mugendi, D.N. (2014). Length of growing season, rainfall temporal distribution, onset and cessation dates in the Kenyan highlands. *Agricultural and Forest Meteorology*, 188, 24–32.

Okeyo, A. I., Mucheru-muna, M., Mugwe, J. and Ngetich, K.F. (2014). Effects of selected soil and water conservation technologies on nutrient losses and maize yields in the central highlands of Kenya. *Agricultural Water Management*, 137, 52–58.

Pagliai, M., Vignozzi, N. and Pellegrini, S. (2004). Soil structure and the effect of management practices. *Soil and Tillage Research*, 79, 131–143.

Palm, C. A., Gachengo, C. N., Delve, R. J., Cadisch, G. and Giller, K. E. (2001). Organic inputs for soil fertility management in tropical agroecosystems: Application of an organic resource database. *Agriculture, Ecosystems and Environment*, 83, 27–42.

Palm, C., Blanco-Canqui, H., DeClerck, F., Gatere, L. and Grace, P. (2014). Conservation agriculture and ecosystem services: An overview. *Agriculture, Ecosystems and Environment*, 187, 87–105.

Palm, C., Sanchez, P., Ahamed, S. and Awiti, A. (2007). Soils: A contemporary perspective. *Annual Review of Environment and Resources*, 32, 99-129.

Paudel, B., Radovich, T. J. K., Chan-Halbrendt, C., Crow, S., Tamang, B. B., Halbrendt, J. and Thapa, K. (2014). Effect of conservation agriculture on maize-based farming system in the mid-hills of Nepal. *Procedia Engineering*, 78, 327–336.

Pinheiro, Erika Flavia Machado, de Campos, D. V. B., de Carvalho Balieiro, F., dos Anjos, L. H. C. and Pereira, M. G. (2015). Tillage systems effects on soil carbon stock and physical fractions of soil organic matter. *Agricultural Systems*, 132; 35–39.

Pittelkow, C. M., Linquist, B. A., Lundy, M. E., Liang, X., van Groenigen, K. J., Lee, J. and van Kessel, C. (2015). When does no-till yield more? A global meta-analysis. *Field Crops Research*, 183, 156–168.

Place, F., Barrett, C. B., Freeman, H. A., Ramisch, J. J. and Vanlauwe, B. (2003). Prospects for integrated soil fertility management using organic and mineral inputs : evidence from smallholder African agricultural systems. *Food Policy*, 28, 365–378.

Powlson, D. S., Bhogal, A., Chambers, B. J., Coleman, K., Macdonald, A. J., Goulding, K. W. T. and Whitmore, A. P. (2012). The potential to increase soil carbon stocks through reduced tillage or organic material additions in England and Wales: A case study. *Agriculture, Ecosystems and Environment*, 146, 23–33.

Preissel, S., Reckling, M., Schläfke, N. and Zander, P. (2015). Magnitude and farm-economic value of grain legume pre-crop benefits in Europe: A review. *Field* Crops *Research*, 175, 64–79.

Pulido-Fernández, M., Schnabel, S., Lavado-Contador, J. F., Miralles Mellado, I. and Ortega Pérez, R. (2013). Soil organic matter of Iberian open woodland rangelands as influenced by vegetation cover and land management. *Catena*, 109, 13–24.

Ranatunga, K., Nation, E. R. and Barratt, D. G. (2008). Review of soil water models and their applications in Australia. *Environmental Modelling and Software*, 23, 1182–1206.

Rasche, F., Musyoki, M. K., C., Muema, E. K., Vanlauwe, B. and Cadisch, G. (2014). Lasting influence of biochemically contrasting organic inputs on abundance and community structure of total and proteolytic bacteria in tropical soils. *Soil Biology and Biochemistry*, 74, 204–213.

Rong, Y., Yong-zhong, S. U., Tao, W. and Qin, Y. (2016). Effect of chemical and organic fertilization on soil carbon and nitrogen accumulation in a newly cultivated farmland. *Journal of Integrative Agriculture*, 15, 658–666.

Rovira P, Vallejo V. R. (2007). Labile, recalcitrant, and inert organic matter in Mediterranean forest soils. *Soil Biology and Biochemistry*, 39, 202–213.

Rowhani, P., Lobell, D.B., Linderman, M., and Ramankutty, N. (2011). Climate variability and crop production in Tanzania. *Agricultural and Forest Meteorology*, 151, 449–460.

Rurangwa, E., Vanlauwe, B. and Giller, K. E. (2017). Benefits of inoculation, P fertilizer and manure on yields of common bean and soybean also increase yield of subsequent maize. *Agriculture, Ecosystems and Environment*, 261, 219-229.

Rusu, T. (2014). Energy efficiency and soil conservation in conventional, minimum tillage and no-tillage. *International Soil and Water Conservation Research*, 2, 42–49.

Rutkowska, B., Sosulski, T., Skowro, M. and Szczepaniak, J. (2018). Impact of reduced tillage on CO2 emission from soil under maize cultivation. *Soil and Tillage Research*, 180, 21–28.

Ryan, J., George E. and Rashid, A. (2001). Soil and Plant Analysis Laboratory Manual. Second edition. Jointly published by international Center for Agricultural

Research in the dry areas (ICARDA) and the National Agricultural Research Centre (NARC), p. 46-48.

Sahin, I., Rogers, F., Rogers, F. and Rogers, F. (2006). Detailed review of Rogers' Diffusion of Innovations Theory and Educational Technology-Related Studies Based on Rogers' Theory. *The Turkish Online Journal of Educational Technology*, 5, 14–23.

Sainju, U. M., Lenssen, A. W., Allen, B. L., Stevens, W. B. and Jabro, J. D. (2017). Soil total carbon and crop yield affected by crop rotation and cultural practice. *Agronomy Journal*, 109, 388–396.

Sanchez, P. A., Shepherd, K. D., Soule, M. J., Place, F. M., Buresh, R. J., Izac, A. N. and . Woomer, P. L. (1997). Soil Fertility Replenishment in Africa: An Investment in Natural Resource Capital Pedro. Replenishing Soil Fertility in Africa, *SSSA Special Publication*, 51, 1–47.

SAS Institute Inc. (2008). SAS/STAT® 9.2 User's Guide. Cary, NC: SAS Institute Inc. p. 1-9481

Serafim B, Oginga B. and Njeri J. (2013). Effects of manure, lime and mineral P fertilizer on soybean yields and soil fertility in a *Humic nitisol* in the Central Highlands of Kenya. *International Journal of Agriculture Science Research*, 2, 283–291.

Seyyedi, S. M., Rezvani Moghaddam, P. and Nassiri M. (2016). Weed Competition Periods Affect Grain Yield and Nutrient Uptake of Black Seed (Nigella Sativa L.). *Horticultural Plant Journal*, 2, 172–180.

Shahbaz, M., Kuzyakov, Y., Sanaullah, M., Heitkamp, F., Zelenev, V., Kumar, A. and Blagodatskaya, E. (2017). Microbial decomposition of soil organic matter is mediated by quality and quantity of crop residues : mechanisms and thresholds. *Biology and Fertility of Soils*, 53, 287–301.

Shahzad, Z. and Amtmann, A. (2017). Food for thought: how nutrients regulate root system architecture. *Current Opinion in Plant Biology*, 39, 80–87.

Shamie Zingore, James Mutegi, Beverly Agesa, Lulseged Tamene, and J. K. (2015). Soil Degradation in sub-Saharan Africa and Crop Production Options for Soil Rehabilitation. *Better Crops*, 99, 65–67.

Shibu ME, Leffelaar PA, Van Keulen H and Aggarwal K (2006). Quantitative description of soil organic matter dynamics – a review of approaches with reference to rice-based cropping systems. *Geoderma* 137, 1–18.

Shrestha, R. P. and Ligonja, P. J. (2015). Social perception of soil conservation bene fi ts in Kondoa eroded area of Tanzania. *International Soil and Water Conservation Research*, 3, 183–195.

Silvia, S., Miura, T., Nobuhiro, K., Fujie, K., Hasanuddin, U., Niswati, A. and Haryani, S. (2014). Soil microbial biomass and diversity amended with bagasse mulch in tillage and no-tillage practices in the sugarcane plantation. *Procedia Environmental Sciences*, 20, 410–417.

Sime, G., Aune, J. B. and Mohammed, H. (2015). Agronomic and economic response of tillage and water conservation management in maize, Central Rift Valley in Ethiopia. S*oil and Tillage Research*, 148, 20–30.

Singh, G., Gillespie, A., Peak, D. and Rees, K. (2017). Spectroscopic investigation of soil organic matter composition for shelterbelt agroforestry systems. *Geoderma*, 298, 1–13.

Singh, V. K. Dwivedia, B. S. Yadvinder-Singh, Singh S. K., Mishra, R. P., Shukla, A. K. Rathore, S. S. Shekhawat, K. Majumdar, K. and Jat, M.L. (2018). Effect of tillage and crop establishment, residue management and K fertilization on yield, K use efficiency and apparent K balance under rice- maize system in north-western India. *Field Crops Research*, 224, 1–12.

Six, J. Elliiott, E.T. and Paustian, K. (2000). Soil macroaggregate turnover and microaggregate formation : A mechanism for C sequestration under no-tillage agriculture soil macroaggregate turnover and microaggregate formation. *Soil Biology and Biochemistry*, 32, 2099–2103.

Smith, A., Snapp, S., Dimes, J., Gwenambira, C. and Chikowo, R. (2016). Doubled-up legume rotations improve soil fertility and maintain productivity under variable conditions in maize-based cropping systems in Malawi. *Agricultural Systems*, 145, 139–149.

Smith, L. E. and Siciliano, G. (2015). A comprehensive review of constraints to improved management of fertilizers in China and mitigation of diffuse water pollution from agriculture. *Agriculture, Ecosystems and Environment*, 209, 15–25.

Strickland, T. C., Potter, T. L., Truman, C. C., Franklin, D. H., Bosch, D. D. and Hawkins, G. L. (2012). Results of rainfall simulation to estimate sediment-bound carbon and nitrogen loss from an Atlantic Coastal Plainc (USA) ultisol. *Soil and Tillage Research*. 122, 12–21.

Ström, G., Albihn, A., Jinnerot, T., Andersson-djurfeldt, A., Sokerya, S., Osbjer, K. and Magnusson, U. (2018). Manure management and public health : sanitary and socio-economic aspects among urban livestock-keepers in Cambodia. *Science of The Total Environment*, 621, 193–200.

Szanser, M., Kusi, A., Kisiel, M. and Sieminiak, D. (2011). Possibility of using diverse plant litter in soil restoration processes. *Procedia Environmental Sciences*, 9, 25–29.

Tao, Z., Li, C., Li, J., Ding, Z., Xu, J., Sun, X., Zhao, M. (2015). Tillage and straw mulching impacts on grain yield and water use efficiency of spring maize in Northern Huang-Huai-Hai Valley. *Crop Journal*, 3, 445–450.

Toosi E.R., Kravchenko A. N, Mao J. and Quigley M.(2017). Effects of management and pore characteristics on organic matter composition of macroaggregates : evidence from characterization of organic matter and imaging. *European Journal of Soil Science*, 68, 200–211.

Townsend, T. J., Ramsden, S. J. and Wilson, P. (2016). Analysing reduced tillage practices within a bio-economic modelling framework. *Agricultural Systems*, 146, 91–102.

Tu, C., Ristaino, J. B. and Hu, S. (2006). Soil microbial biomass and activity in organic tomato farming systems: Effects of organic inputs and straw mulching. *Soil Biology and Biochemistry*, 38, 247–255.

Tully, K., Sullivan, C., Weil, R. and Sanchez, P. (2015). The State of Soil Degradation in Sub-Saharan Africa: Baselines, Trajectories, and Solutions. *Sustainability*, 7, 6523–6552.

Vaclav Tejnecky, Nand'a Revichova, Monika Brandova, Katel Nemecek, Hana Santruckova, and Christopher A. O. D. (2014). Litter decomposition as a source of active phosphates in spruce and beech mountainous forests affected by acidification. *Procedia Earth and Planetary Science*, 10, 130–132.

Valeem, E. V. and Farooqui. (2009). Variations in The Leaf Litter Decomposition in Tidal Mudflats Of Nara Creek , Indus Delta. *International Journal of Phycology and Phycochemistry*, 5, 143–148.

Vanlauwe, B. and Giller, K. E. (2006). Popular myths around soil fertility management in sub-Saharan Africa. *Agriculture, Ecosystems and Environment*, 116, 34–46.

Venkatesh, V., Thong, J. and Xu, X. (2012). Consumer acceptance and user of information technology: Extending the unified theory of acceptance and use of technology. *MIS Quarterly*, 36, 157–178.

Wendt, J. W. and Hauser, S. (2013). An equivalent soil mass procedure for monitoring soil organic carbon in multiple soil layers. *European Journal of Soil Science*, 64, 58–65.

Ward, P. S., Bell, A. R., Droppelmann, K. and Benton, T. G. (2018). Early adoption of conservation agriculture practices: Understanding partial compliance in programs with multiple adoption decisions, *Land use policy* 70, 27–37.

Wollni, M. and Andersson, C. (2014). Spatial patterns of organic agriculture adoption: Evidence from Honduras. *Ecological. Economics*, 97, 120–128.

Wopereis, M. C. S., Tamélokpo, A., Ezui, K., Gnakpénou, D., Fofana, B. and Breman, H. (2006). Mineral fertilizer management of maize on farmer fields differing in organic inputs in the West African savanna. *Field Crops Research*, 96, 355–362.

Xia, M., Talhelm, A. F. and Pregitzer, K. S. (2017). Soil Biology and Biochemistry Chronic nitrogen deposition in fl uences the chemical dynamics of leaf litter and fi ne roots during decomposition. *Soil Biology and Biochemistry*, 112, 24–34.

Yang, R., Su, Y.Z., Wang, T. and Yang, Q. (2016). Effect of chemical and organic fertilization on soil carbon and nitrogen accumulation in a newly cultivated farmland. *Journal of Integrative Agriculture*, 15, 658–666.

Yang, Xue-yun, B. S., and Zhang, S. (2014). Trends of yield and soil fertility in a long-term wheat-maize system trends of yield and soil fertility in a long-term wheat-maize system. *Journal of Integrative Agriculture*, 3, 402–412.

Yang, Z., Zhou, L., Sun, D., Li, H., Cao, J., and Ling, Q. (2011). The effect of cow dung and Red Bean straw Dosage on soil nutrients and microbial biomass in Chestnut orchards. *Procedia Environmental Sciences*, 10, 1071–1077.

Yeganehpoor, F., Salmasi, S. Z., Abedi, G., Samadiyan, F. and Beyginiya, V. (2015). Effects of cover crops and weed management on corn yield. *Journal of the Saudi Society of Agricultural Sciences*, 14, 178–181.

Zhang H M, Wang B R, Xu M G. and Fan T L. (2009). Crop yield and soil responses to long-term fertilization on a red soil in Southern China. *Pedosphere*, 19, 199–207.

Zhang, X., Zhu, A., Xin, X., Yang, W., Zhang, J. and Ding, S. (2018). Tillage and residue management for long-term wheat-maize cropping in the North China Plain : I. Crop yield and integrated soil fertility index, *Field Crops Research*, 221, 157–165.

Zhang, Z. yong, Zhang, X. ke, Jhao, J., Zhang, X. and Liang, W. (2015). Tillage and rotation effects on community composition and metabolic footprints of soil nematodes in a black soil. *European Journal of Soil Biology*, 66, 40–48.

Zingore, S., Mutegi, J., Agesa, B., Tamene, L. And Kihara, J. 2015. Soil degradation in sub-Saharan Africa and crop production options for soil rehabilitation. *Better Crops with Plant Food*, 99, 65–67.

Appendices

Appendix 1: Interview guide

Interview schedule on assessment of the likelihood of farmers' to take up the selected soil fertility management technologies in Tharaka-Nithi and Muranga Counties.

We thank you so much for participating in the implementation of soil fertility management technologies and request that we talk about your experience with the technologies. The shared information will assist me in writing my thesis and to come up with better ways of improving soil fertility status. I am a Master of Science student at University of Embu pursuing a degree in Soil Science. My study focuses on soil fertility management measures implemented in the farmers' fields. The information will be handle with utmost confidentiality and personal details will not be published anywhere.

Date of interview:_ _/_ _/2016 Sub-county.. Village: ………………………..…………

Start Time _ _:_ _ GPS coordinates: _ _º_ _'_ _'' S _ _º_ _'_ _'' E

Questions are addressed to the respondent involved in the training and implementation of the soil fertility management technology.

Phone Number: ……………………….....................

Core var. no	Variable labels	*Variable values and rules*
	Household Demographic and Socioeconomic Characteristics	
1	Name of the household head ____	
2	Relationship of the respondent to the household head	*1=Household head* *2=Spouse of the household head* *3=Grown up child* *4=Relative* *5= Other (specify)*

3	Household type ______________	*1=☐Nuclear* *2=☐Extended* *3=☐Polygamous* *4=☐Female headed (widow, never married, divorced)* *5=☐(male headed)* *6=☐Not yet married males/Females*
4	Gender of household head (Decision maker of farm operations) ___________	*Tick where applicable* *1=☐Male* *2=☐female*
5	Age of household head _________ years	
6	Educational levels of the Household Head __________	*1=☐no formal education* *2=☐primary education* *3=☐secondary education* *4=☐tertiary education (Specify)*
7	Gender of the household member involved in implementing the SFM technology _____	*1=Male* *2= Female* *3= both*
8	How many years of farming experience	*1=☐less than 10 years* *2=☐11-20 years* *3=☐Above 20 years*
9	What is your total farm size?___________acres	
10	How much of your land is cultivated? ________acres	

Sn.No.	Questions	Follow-up questions	Supplementary notes
a. Farm data			
1	Who is the main decision-maker on this farm?	Who decides what inputs to use on the farm? Does the decision maker support INMT?	
2	How long have you been farming?	Do you think the experience you have gained can help you choose the best SOIL FERTILITYimprovement technique for your farm?	
3	Where do you get labour?	Is this family labour or hired labour? Do you discuss with them about INMT?	
4	What is the size of your farm? (In acres)..........................	Is there a portion of the land for agricultural expansion?	
5	What is the land tenure status of your farm? Communal...... Own................ Leased...........	Does the tenure affect your SOIL FERTILITYmanagement activities? Which SOIL FERTILITYinputs do/would you use in leased farm? And which ones do/would you use on own land?	

6	What are your main crops? Cash crops.. Food crops...	Cash crops... .... Food crops..	
7	Would crop type influence the choice of fertilization inputs you use?	Which inputs for cash crops? And which ones for food crops?	
8	Do you keep livestock?	How many in total? Approximately how much of manure do you get from them?	
9	How do you feed your livestock?	(Using residues as fodder?) Does the way you feed your livestock affect the way you manage crop residues? How?	
b. Factors influencing SOIL FERTILITYManagement Decision			
10	What are your sources of non-farming income?	Do these sources influence SOIL FERTILITYmanagement decision? How?	
11	Food security: Do you produce enough of the main crops for your household consumption?	If NO, why? If Yes, what do you do?	
12	Does your production level influence your SFM decision?	What choice of SOIL FERTILITYinputs would improve your production level?	
c. Likelihood of INMT up-take			
13	Quality of soil: How would you rate the quality of soils on your farm?	If good, what SOIL FERTILITYimprovement measures do you use to maintain or improve it? If bad, what is the previous SOIL FERTILITYimprovement measures used?	
14	What are the advantages and disadvantages Of SOIL FERTILITYimprovement measures used above?		
15	Do you use organic inputs on your farm?	If YES, which ones? What is your experience using OIs?	
16	Are organic inputs readily available within the village?	Are there situations where farmers obtain OIs from other place? Do they buy?	
17	Do you know any of the following options for soil fertility management? Minimum tillage Mulching (C. residues)	Minimum tillage Mulching (C. residues) Goat manure Legumes intercropping Biomass transfer *(Tithonia diversifolia)*	

	Goat manure Legumes intercropping Biomass transfer *(Tithonia diversifolia)* INMT *(judicial combination of OIs and* Mineral*inputs)*	INMT	
18	Have your tried these methods at any one time?	*Would you wish to explore various ways of combining the* SOIL FERTILITY*inputs?*	
19	Which one of the INMT you implemented do you think is suiTable for your village?	Please explain.	
20	What are the *main hindrances* to the implementation of the techniques you implemented?		
21	What do you think should change in order to make these techniques effective?		
22	Multiplicity effect: Have you discussed the benefits of the techniques you implemented with other people?	Have other farmers in your village taken up this technique? How many? Did you involve other family members in implementing the techniques?	
23	Will you modify the techniques to suit your expectations?	If YES, in what way(s)?	
24	Having been part of implementing INMT, do you still feel you need extension services for more support?	Will these services help you in adopting SFM techniques? How?	
25	In your opinion, how different is the current devolved extension services to the old system?	Is it better or worse? How?	

End Time: _ _: _ _

I am very grateful for your time and honest corporation in answering our questions. We shall share with you the findings of our research and hope that some of the results will be useful to you and the community in addressing soil fertility problems.

THANK YOU!