ZAI PITS AND INTEGRATED SOIL FERTILITY MANAGEMENT ENHANCES CROP YIELDS IN THE DRIER PARTS OF THARAKA NITHI COUNTY, KENYA

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DECLARATION

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

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I dedicate this thesis to my loving husband Benson Muchai and our three daughters, Vivian Wanjiru, Asher Wanjiku and Purity Wambui. Thank you for your support.

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Everything I have achieved has only been possible because of the blessings of God, and I say ―To God be all the Glory!!

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ABBREVIATIONS AND ACRONYMS

ANOVA	Analysis of Variance
ASAL	Arid and Semi arid areas
CF	Conservation Farming
EABL	East Africa Breweries Limited
FAO	Food and Agriculture Organization
GM	Gross margin
ISFM	Integrated Soil Fertility Management
KARI	Kenya Agricultural Research Institute
KASAL	Kenya Arid and Semi-Arid Lands programme
KES	Kenya Shillings
LR14	Long rain 2014
LSD	Least Significant difference
NGO	Non-government organization
RWHM	Rain water harvesting management
SR13	Short rains 2013
SR14	Short rain 2014
SSA	Sub-Saharan Africa
TR	Total revenue
TVC	Total Variable cost
US$	US Dollars
VWC	Volumetric water content
WHT	Water Harvesting Technologies

ABSTRACT

Low crop yields due to low erratic rainfall, high evapotranspiration, and deteriorating soil fertility in smallholder farmers' fields of sub-Saharan Africa have led to a quest for sustainable production practices with greater resource use efficiency. To alleviate water stress, soil fertility decline and reduce runoff, water harvesting technologies and integrated soil fertility management (ISFM) are alternative promising options whose impact on agricultural productivity are not yet clear. The study therefore aimed to assess the effect of using zai pits in combination with organic/inorganic ammendments and conventional cropping technique on sorghum production. Effects of zai pit and conventional cropping techniques combined with integrated soil fertility management (ISFM) (organic materials as sole or combined with inorganic fertilizer) on selected soil physico-chemical properties and sorghum yields were assessed in a field experiment. Economic performance of all the treatments was evaluated using standard enterprise budgeting techniques to determine production costs and profitability. Descriptive statistics, chi-square, paired t tests and binary logistic regression were used in analysis of socio-economic data. Experimental data were subjected to analysis of variance and mean separation done using least significant difference (LSD) at $p<0.05$. The results of the study indicated that number of non-formal trainings, beneficiaries of NGOs, membership of group and visits by non-governmental extension agents play an important role in adoption of zai pits. Manure application led to a significant ($p=0.014$) increase in pH and a significant ($p=0.05$) increase in nitrogen under zai pit. The aggregate stability of zai and sole tithonia (ZT) was significantly higher ($p=0.03$) than conventional planting with sole tithonia (CT) at the end of the experiment. High volumetric water content (VWC) was recorded at the depth of 35 cm for zai treatments compared to conventional treatments. Zai pit in combination with tithonia amendment had the highest yields of 4.3 Mg ha^{-1} during short rains season of 2013 (SR13) while zai pit in combination with cattle manure had the highest yield of 4.18 Mg ha^{-1} during short rains season of 2014 (SR14). During the SR14, grain yields of zai pit with cattle manure (ZC) were significantly ($p=0.016$) higher by 53.7% compared to conventional planting with cattle manure (CCM). Conventional planting with full rate NPK (CF60) had the highest benefit cost ratio (BCR) of 3.58 while zai pit without input (ZNO) had the least BCR of 0.94. The experiment showed that zai pit technology contributed to increments of grain and stover yields in comparison to conventional planting although its BCR was lower than conventional planting with similar amendments. Based on the findings, there is need for agricultural policy makers to develop and implement appropriate agricultural guidelines for extension service providers and smallholder farmers on the effectiveness and efficiency of the technologies in the study. This will enable small holder farmers to make informed decisions on adoption of the technologies as a coping mechanism to climate change, enhancement of food security and alleviation of poverty in in the semi-arid tropics in Sub Saharan Africa.

CHAPTER 1

INTRODUCTION

1.1. Background of the study

Inadequate water and low nutrient supply have been major constraints that impinge crop productivity in the world (Hengsdijk and Langeveld, 2009). Along with low nutrient status, soil moisture stress is another most critical constraints that has caused decline or stagnation of crop production (Rockstrom *et al*., 2010). Moreover, high frequency of dry spells and droughts that characterize rainfed agriculture in Africa (Rockstrom *et al*., 2010) threaten national food demand projected by 2050 (Grafton *et al*., 2015). Similarly, Intergovernmental Panel on Climate Change (IPCC, 2007) reports a high level of confidence that agriculture production will be severely affected by climate change. Rain-fed agriculture in Africa is viewed as the most vulnerable sector to climate variability.

In Kenya, low soil fertility and moisture deficits are major constraints to crop production in the semi-arid areas (Gichangi *et al*., 2006). Kenya has had significant droughts in 1971-73, 1983-84, 1991-2 and most recently 2004-6, affecting food availability for 2.5 million people, and 2008-10, affecting 10 million people (Rarieya and Fortun, 2009). Current average global crop yield growth of the world's major cereals varies between 0.9 % and 1.6 % per year, and the rates of increase have fallen in the past two decades (Grafton *et al*., 2015). In developing countries, rainfed grain yields average 1.5 t ha^{-1} compared with 3.1 t ha^{-1} in irrigated agriculture (Rosegrant *et al*., 2002). Conversely, in tropical regions with reliable rainfall and sufficient nutrient, rainfed agriculture exceed 5–6 t/ha (Wani *et al*., 2003).

The yield gap between the actual harvests being gathered from farmers' fields and what could be possibly achieved attests the need to develop new strategies of agricultural production in sub-Saharan Africa. These experiences suggest that the challenges of low yields in rainfed farming systems in developing countries might be overcome with nutrient management combined with soil water conservation (Rockstrom *et al.,* 2010). Incorporating water harvesting technologies with improved soil fertility management methods generates synergies that further increase water efficiency and yields in smallholder farms (Winterbottom *et al*., 2013). Use of suitable water and soil management techniques such as zai pit (Evett and Tolk, 2009) increase rainfall use efficiency and bridge intraseasonal dry spells (Dile *et al*., 2013).

Zai pit (also called tassa in Niger or towalen in Mali) is one of the successful interventions that improve precipitation capture, reduce runoff and evaporation, and improve agricultural productivity (Evett and Tolk, 2009). Since most cultivated lands are characterized by crusted soils, hardpan formation, compaction, inadequate aeration, reduced permeability and limited plant root development (Zougmoré *et al*., 2014), pit digging facilitates more water infiltration and runoff water is harvested due to the earthen bund formed downslope of the pits (Kaboré and Reij, 2004). However, zai pits have been known to be more effective while in combination with organics and inorganics (Burpee *et al*., 2015). Application of organic and inorganic inputs not only enhances soil nutrient availability but also improves crop nutrient uptake from soil reserves (Kar *et al*., 2013).

Manure application with zai pits, in Niger, has shown a 2–69 times better grain yields than pits with no nutrient amendment (Fatondji *et al*., 2006). Other studies reported that applying compost with mineral fertilizers allowed substantial gain in sorghum grain yields compared to zai pits without any organic or mineral supply (Roose *et al*., 1999, Reij *et al*., 2009). In Machakos County, Kenya, zai pits without fertiliser application significantly (p = 0.05) increased sorghum grain yields by ten times over the plot without zai pits and with no fertiliser during the 1995 short rains (Kathuli and Itabari, 2014). The improvement of water status in the soil and the increased decomposition and nutrient release result into a beneficial impact of the zai systems on crop performance under semiarid conditions (Zougmoré *et al*., 2014). While most of the studies related to zai system has been carried out in the Sahelian region of West Africa there are limited studies done in Eastern Africa. Hence the focus of this study is zai pit as a technique that conserves moisture and restores soil fertility in the semi-arid and arid areas using sorghum as a test crop.

1.2. Problem Statement

Low soil fertility and water stress are key factors that hamper rainfed agriculture in low midland zones of Tharaka Nithi County (Kisaka *et al*., 2015). Water harvesting and soil fertility management technologies are currently being promoted in the region as a measure to conserve moisture, mitigate effect of droughts, improve soil fertility and ultimately increase crop productivity (Mati, 2005). However, despite the efforts that have been put by the Ministry of Agriculture and other developmental organizations in promotion of the technologies, adoption by the farmers is still low (Nyamadzawo *et al*., 2013; Recha *et al*., 2015**)**. This has necessitated the need to evaluate the factors that influence adoption of zai pits at household level. In addition, very little information exists or is documented on the impact of combined zai pits and organic/inorganic soil fertility management options on crop yields. While various studies in Africa provide useful insight on impact of zai pits in production of cereal crops (Fatondji, 2002; Kaboré and Reij, 2004), little research has been conducted to evaluate their impacts on sorghum's productivity and economic returns in marginal, low-midland agro-ecological zones. To ascertain utilization of zai pits in combination with different soil fertility management amendments on crop production there is need to evaluate their effects on soil fertility, yields, as well as their economic feasibility.

1.3 Objectives

The main objective of this study was to assess the effect of using zai pits in combination with organic / inorganic materials on sorghum production in the low midland zones of Tharaka-Nithi County.

The specific objectives were;

1. To analyse socio-economic factors that influence adoption of zai pits by farmers in Tharaka Nithi County
2. To determine the effects of zai pits and organic / inorganic amendments on soil pH, soil organic carbon, nitrogen content, aggregate stability and soil moisture
3. To assess the effects of zai pits in combination with selected organic / inorganic amendments on sorghum yields
4. To evaluate the economic returns of zai pits utilization in combination with selected organic / inorganic amendments on sorghum production

1.4 Hypotheses

The study was guided by the following hypotheses:

1. There is a significant relationship between adoption of zai pits and age, gender and education level of farmers
2. Zai pits in combination with organic amendments have significant effect on soil pH, soil organic carbon, nitrogen content, aggregate soil stability and soil moisture
3. Zai pits in combination with organic/ inorganic amendments significantly increase on sorghum yields
4. Utilization of zai pits in combination with organic/ inorganic amendments will significantly increase the economic returns of sorghum production

1.5 Significance and Anticipated Output

The information gathered in this study will provide useful feedback to farmers and extension agents on zai pits design and implementation. For instance, factors found to be positively influencing adoption of water harvesting structures if targeted would be important at enhancing high agricultural production. It is also expected that the results will be useful to extension service providers in planning, designing and evaluating effective and efficient agricultural policies, programs and projects at local, regional and national scales for the small holder farmers in the sub-humid and semi-arid tropics in the Sub Saharan Africa. The findings will give insight to small holder farmers in choosing appropriate technologies for soil fertility improvement, water harvesting, yields increment and economic efficiency as a strategy for food security mitigation as well as alleviation of poverty.

1.6 Definition of terms

Adoption	Implementation of zai pit as an innovation since 2011
Amendment	source of soil nutrients
Conventional planting	farming without the use of zai pits
Technology	improved agricultural practice
Treatment	unique experimental unit
Variable cost	expense that varies with production output
Zai pits	Pits with a diameter and depth of 60 cm by 60cm
Marginal Farmer	a farmer cultivating agricultural land up to 1 hectare

1.7 Conceptual Framework

Semi-arid regions are characterized by low erratic rainfall, poor nutrient soils and high temperatures that pose serious limitations in crop productivity especially when water supply is inadequate (Altieri and Koohafkan, 2008). This can be manifested through poor development of crop yield structures and ultimately low yields (Figure 1.1). A number of water harvesting technologies with organic/ inorganic amendments throughout the semi-arid areas have been developed by researchers, non-government organizations (NGO) (Campbell *et al*., 2014) and others as a result of farmers innovations. Promoted technologies such as zai pits integrated with organic/ inorganic amendments are multi-functional as their adoption usually means simultaneous changes in various components of farming systems (Figure 1.1). In addition to enhancing water infiltration and increase of soil moisture retention, the technologies secure favorable soil conditions for plant growth, through improved organic matter content, soil biotic activity and consequently increased crop productivity (Figure 1.1). Farmers who use these technologies are likely to cope with the effects of climate variability and soil degradation such as low yields during severe dry spells. The conceptual framework (Figure1.1) shows effects of water harvesting technologies such as zai pits integrated with organic/ inorganic amendments in agricultural production in low midland zones of Tharaka Nithi County. Adoption of water harvesting techniques integrated with organic/ inorganic amendments will lead increased food security, farm income and ultimately reduction of poverty among smallholder farmers.

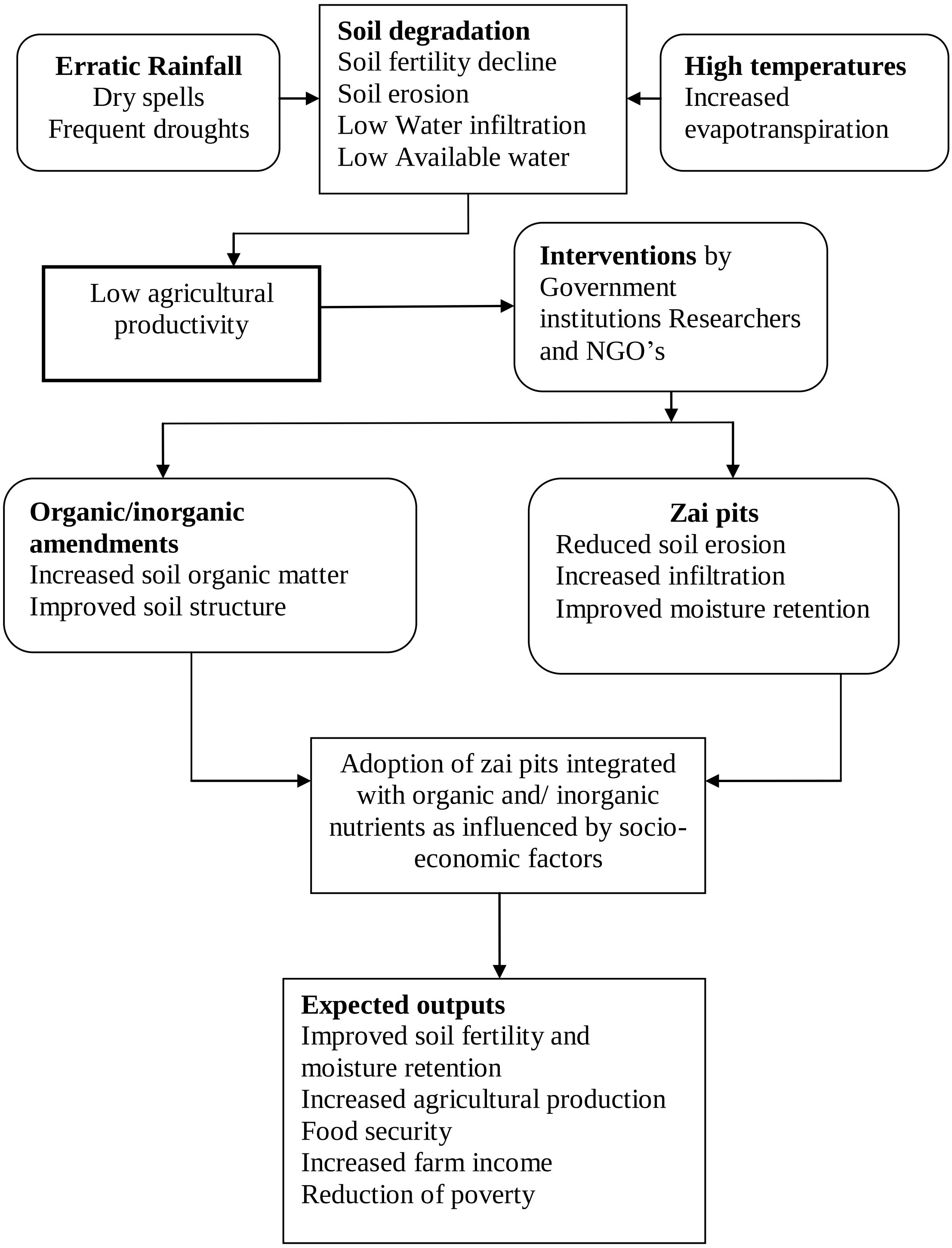

Figure 1.1 Conceptual framework showing effects of water harvesting technologies combined with organic/ inorganic amendments in Tharaka-Nithi County (source; Author)

CHAPTER 2

LITERATURE REVIEW

2.1 Over view

Majority of the smallholder farmers in Kenya in the Arid and Semi-arid areas depend on crop production and livestock keeping for subsistence. These activities face many constraints due to unreleliable rainfall and high rate of evapotranspiration, limit crop growth further reducing yields (Altieri and Koohafkan, 2008). To offset crop failure arising from rainfall variability and unpredictability, farmers have opted to adopt soil and water harvesting techniques to conseve soil and increase water infiltration as well as replenish soil fertility (Biamah, 2005). Research indicates that soil nutrient deficiency is often equally limiting to crop growth as water scarcity in semi-arid farming systems (Breman *et al*., 2001; Fox and Rockstrom, 2003). Water and nutrients thus interact in limiting crop growth. However, water has been considered as the key factor determining risk perceptions of harvest loss among farmers (Fox *et al*., 2005).

Due to high rainfall variability typical of the semiarid tropics (GoK, 2005) farmers relie on stable crops such as millet and sorghum grown in mixed stands with legumes such as green gram, beans, cowpea and pigeon pea. Lack of enough soil moisture is one of the major constraints to land productivity in the semi-arid lands of Kenya (Itabari *et al*., 2004). Research conducted in this region over the years has pointed out that rainwater harvesting in combination with soil fertility amendments significantly increase crop production (Itabari and Wamuongo, 2003; Gichangi *et al*., 2007).

Sorghum and millets are among the most embraced drought tolerant traditional food crops in the arid and semiarid areas (Taylor, 2003). However, their production potential has not been adequently exploited due to frequent famines in the regions. Hence it is paramount to search for more efficient water harvesting innovations to improve on rainfall management in sustainable and integrated production systems. This will enhance the small-scale farmers' livelihood by upgrading the rainfed agricultural production (CASL, 2006).

2.1.1 Sorghum Production

Grain sorghum is ranked as the fifth most important cereal crop grown in the world (U.S Grain Council, 2011) and it is the second most important cereal food after maize for the millions of people living in the arid and semiarid regions of Africa (Taylor, 2003). In Kenya, sorghum is an important food crop in the dry land areas of Eastern Coast and Nyanza provinces. Sorghum production has widely been promoted in the arid and semi-arid regions due to it tolerance to drought, ability to thrive well in a range of soils and low input requirements, compared with most staple cereals like maize (Mwadalu and Mwangi, 2013). Sorghum promotion is mainly done as a strategy to enable the government meet household food security needs and increase rural income among the small holder farmers in the semi-arid areas of Kenya (Ochieng *et al*., 2011). In recent years, sorghum has been on demand within the brewing industry as a best alternative to barley for larger scale beer brewing (Taylor, 2010).

Gadam sorghum variety was introduced by Kenya Agricultural and Livestock Research Organization (*KALRO)* formerly, Kenya Agricultural Research Institute (KARI) to semiarid Eastern Kenya in 2009 as a way for farmers to reduce food insecurity and better their lives from the sales of produce (Esipisu, 2011). Gadam has high yields, maturing early and is drought resistant (Esipisu, 2011). The grain of gadam sorghum is low in protein and high in starch, which makes it suitable for malting (Miano *et al*., 2010). Despite the efforts put in promotion of Gadam sorghum, there has been variability in production from the expected potential yields and the actual yields (Chepng'etich *et al*., 2014). The expected potential yield for the Gadam sorghum variety is 4-5 tons ha^{-1} (KARI, 2006). Unfortunately farmers have only realized production of up to 1.2 tons ha^{-1} (GoK, 2009; Karanja *et al*., 2009). The low current production is due to the erratic rainfall and low use of inputs to boost soil fertility among other factors (Miano *et al*., 2010; Muui *et al*., 2013). It is for this reason that the study opted to use Gadam sorghum as its test crop and assess its potential yields using zai pit soil water conservation technique with different inputs as soil fertility amendments.

2.1.2 Effects of water scarcity on agricultural productivity in the ASAL

In semi-arid regions, water scarcity has been a major impediment to rainfed agriculture. Low crop productivity in semi-arid areas is due to marginal and erratic rainfall, exacerbated by high runoff and evaporation losses (Mzezewa *et al*., 2011) among other factors. Bahri *et al.* (2011) pointed out that Africa has a particularly high spatial and temporal variability in rainfall when compared with other continents**.** Marginal and highly variable rainfall combined with unpredictable droughts largely influence economics of agricultural production among the smallholder farmers in the rural areas (Mutekwa, 2009). Dry spells which is a common phenomenon in the semi-arid areas increases water evaporation losses, disturb the root uptake capacity of the crop and consequentially lead to low yields

(Fox and Rockstrom, 2003). Increasing the productivity of rain-fed systems in the arid and semi- arid areas of Africa will be crucial as they cover the majority of agricultural lands. Alongside seizing viable irrigation opportunities there is need to intergrate rainwater management to complement soil moisture deficit in the semi arid areas. Managing the risk associated with rainfall variability is a promising option to increase productivity.

In order to deal with the challenge of water scarcity which is a threat to food security, water harvesting techniques are being used in water management for rainfed agriculture (Mati, 2005). In a series of case studies by International Center for Agricultural Research in the Dry Areas (ICARDA), improved land and water management practices have shown to reduce yield gaps (Pala *et al*., 2011). Furthermore, improved water management can be a catalyst for economic growth among the rural farmers in the semi arid areas. Researchers have provided a vast array of options to address the challenge of water scarcity and enhance agricultural productivity in the semi-arid areas. Among the water harvesting techniques are zai pits, negarims, semi-circular bunds and half moons (Nyamadzawo *et a*l., 2013). This study embarks on zai pit as a soil water harvesting technique promoted in the semi arid areas of Kenya.

2.1.3 Zai pits

Zai pit system is efficient in alleviating the effects of drought and it meets the criteria for three types of conservation practices – soil maintenance, water preservation, and erosion control. A “zai” is a hole dug in the ground but of different sizes depending on innovation by farmers of different regions. Zai pits are technologies originally practiced in Burkina Faso although some literature points it to Dogon in Northern Mali (Danjuma and Mohammed, 2015). Zai system has been has been intensively promoted by NGOs and other international organizations in Zvishavane and Chivi districts, in Zimbabwe (Gumbo *et al*., 2012). The system is also applied in Niger (Fatondji *et al*., 2009), South Africa (Magombeyi, and Taigbenu, 2008), Zambia (Haggblade and Tembo, 2003; Thierfelder *and* Wall, 2009) and Ethiopia (Amede *et al*., 2011).

In Kenya, most farmers know zai as the "five by nine" pit whose metric dimensions is 0.6 m long by 0.6 m wide by 0.6 m deep (Kathuli and Itabari, 2015). These pits are slightly larger than the conventional zai. The "five by nine" refers to the five maize seeds (for dry areas) or nine maize seeds (for wet areas) planted at the pit diagonals (Mati, 2005). This type of pit can be re-used for a period of up to 3 years consequently (Mati, 2005). The pits are spaced 0.6-0.8 m and dug in alternate rows to increase the capture of runoff water (Mati, 2005; Sidibe, 2005). In each zai, the farmer places a mixture of soil and organic matter and then places the seed or the seedling.

In Kenya, zai pits technology has been promoted as a water harvesting technique for maize production in the coastal region (Saha *et al*., 2007) and also in the eastern region (Recha *et al*., 2015). A variation of the zai pit technique known as Tumbukiza has been widely used by smallholder farmers in western Kenya as an alternative method of napier grass production (Orodho, 2007). Variations of zai pits have been used in several areas of Kenya including the katumani pit and "five by nine" pit in Murang'a and Machakos Counties (Malesu *et al*., 2007). The size of zai pit in the current study was 60cm by 60cm by 60cm also referred to as five by nine by farmers in Tharaka Nithi. The objective of the study was to evaluate the effect of zai pits and selected soil fertility amendments on soil fertility and sorghum yields.

2.2 Soil fertility amendment options

Low soil fertility is a major limitation to rainfed agriculture in smallholder farming in Africa (Vanlauwe and Giller, 2006). Nutrient depletion for several decades in SSA have transformed originally fertile lands that yielded between 2 t ha^{-1} and 4 t ha^{-1} of cereal grain, into infertile lands where cereal crops yields less than 1t ha^{-1} (Buresh *et al.*, 1996). For soils to be restored to sufficient level of fertility, improved soil-fertility management technologies have been widely promoted by research system among the small holder framers. The soil fertility interventions entails use of mineral fertilizer and organics such as animal manure and green manure (Mugwe *et al.*, 2009). The organics and inorganic fertilizers may be used solely or combined. These practices enable farmers to intensify their production and thereby increase economic benefits due to increased yields. However, practices such as water harvesting technologies are only profitable in fertile soils than in depleted ones (Sanchez *et al.*, 1997). As a result there is need to invest more in soil fertility management as well as in water harvesting to make farming worthwhile in the arid and semi-arid areas.

Combination of zai pits with soil fertility ammendents has been known to promote soil fertility (Fatondji *et al.*, 2006; Sawadogo, 2011). According to Barry *et al.* (2009) there was showed a systematic improvement of soils fertility under zai treatment after 3 and 5 years. Organic matter content, for instance increased from 1 to 1.4% and nitrogen increased from 0.05 to 0.8% (Baary *et al.*, 2009). Soil structure also improved considerably with an increase in its clay content and a decrease in the sand fraction (Barry *et al.,* 2009). The concentration of run-off water, organic manure supplemented with mineral nutrients in the pits increase biomass production which rehabilitate poorly structured soils in the long run (Roose *et al*., 1999). The zai technique is particularly promising when soils are very poor and compacted (Maatman *et al*., 1998). The present study was therefore conducted to investigate the effect of zai pits in combination with different soil fertility ammendments on soil fertility.

2.2.1 Cattle manure

Cattle manure is mostly available as it is produced in farms and is an important organic resource for agricultural production in livestock based farming system in many countries including semi-arid areas of Kenya (Gichangi *et al*., 2007). It is an alternative source of fertility and especially because of the high cost of commercial inorganic fertilizers (Muui *et al*., 2013) and its long term effects on soil properties. Besides supplying macronutrients and micronutrients to the soil (Negassa *et al*., 2001; Tirol-Padre *et al*., 2007) cattle manure also improves the physico-chemical properties of the soil (Tirol-Padre *et al*., 2007). It contains all the nutrients needed for crop growth including trace elements. Nutrient analysis of the manures show that 5 t ha^{-1} cattle manure can supply approximately 58 kg N, 11 kg P, 39 kg K, 44 kg Ca and 13 kg Mg ha^{-1}, but this potential particularly for N, K, Ca and Mg varies across farms Nyambati (2002). In a study conducted by Mucheru-Muna *et al.* (2007) treatments receiving manure had increased pH, SOC concentration, and exchangeable Ca^{2+} and K^{+}. Cattle manure is a key resource in this regard (Bayu *et al.*, 2005), supplying nutrients, raising soil pH, and increasing soil organic carbon. Cattle manure has been known to provide higher P levels to soil as compared to other organic inputs (Opala *et al*., 2012). By raising soil organic matter, it increases cation exchange capacity and improves soil physical properties, such as soil structure (Bationo *et al*., 2006). However, the responses to cattle manure application are highly variable due to differences in the chemical composition of the manures and the rates and frequency of manure application (Gilbert *et al*., 1997).

The chemical composition of cattle manures differs because of variation in animal diet and manure storage and handling (Yang and Ha, 2013). Poor storage conditions may result in ammonia losses through volatilization and leaching of nitrate (Shepherd *et al*., 2002). However, unless it is integrated with inorganic fertilizers, the use of cattle manure alone may not fully satisfy crop nutrient demand, especially in the year of application (Patel *et al*., 2000).

Gateri *et al*. (2011) found that cattle manure generally increased sorghum yields by providing plant nutrients and increasing the soil's capacity to hold those nutrients and also by improving soil physical properties such as the water holding capacity and infiltration rates. In India, application of cattle manure, positively influenced wheat grain and straw yield (Coventry *et al*., 2011). Increase of yields due to use of animal manure has also been reported in other studies of central Kenya (Kimani *et al*., 2004; Lekasi *et al*., 2003). There was therefore a need to evaluate how yields and soil nutrients are affected using cattle manure on both conventional planting and zai pit soil water conservation technique in the study area.

2.2.2 Tithonia diversifolia

Research confirm that *Tithonia diversifolia* is an effective organic amendment for soil fertility improvement and crop yield increment in Kenya (Jama *et al*., 2000), Tanzania (Ikerra *et al*., 2006), Nigeria (Olabode *et al*., 2007), Vietnam (Cong and Merckx, 2005) and many parts of the humid and sub-humid tropics. It originates from Mexico and its now wildly distributed in Africa, Asia and South America (Jama *et al*., 2000). In Kenya, *Tithonia diversifolia* is seen growing as a pure stand or among vegetation along roadsides and river banks. Smallholder farmers use *T. Diversifolia* as hedges on farm boarders. *T. diversifolia* is also rich in nutrients averaging about 3.5% N, 0.37% P and 4.1% K on a dry matter basis (Jama *et al*., 2000). The use of 2tha^{-1} can supply about 70 kg N, 7.4 kg P, 82 kg K, 36 kg Ca and 8 kg Mg ha^{-1}. Soils under tithonia hedges tend to be higher in exchangeable Ca and Mg than soils in adjacent cropped land with no recent use of fertilizer and manure (Jama *et al*., 2000).

Research by Sharrock *et al*. (2004) confirmed *T. diversifolia* to have a high degree of mycorrhizal colonization therefore making it an effective accumulator of phosphorus and other nutrients. Although it is not a legume, the fresh leaf biomass of tithonia has levels of N as high as those found in many N-fixing legumes. Mucheru-Muna *et al*. (2007) reported that, tithonia combined with 30 kg N ha^{-1} from inorganic fertilizer gave a maize grain yield of 5.5 t ha^{-1}, while the control yielded 1.5 t ha^{-1}. Other studies also observed that better crop yields were obtained using tithonia (Ademiluyi and Omotosho, 2007; Olabode *et al*., 2007). Another study by Mutegi *et al*. (2012) reported higher maize grain yields as compared to other treatments other than calliandra. Improved crop performance observed in tithonia treated plots over the control could have resulted from an increased N availability and beneficial effects of applied organic matter. Many studies have been conducted on the effect of *T. diversifolia* under conventional practices but little is known on its effect on soil fertility and yields when incorporated in zai pits.

2.2.3 Inorganic Fertilizers use

Mineral fertilizers amend soil fertility by increasing soil nutrients and enhance the productivity of crops. Use of inorganic fertilizer rehabilitates farms that have been degraded for many years without replenishment leading to low soil quality and ultimately low crop yields (Okalebo *et al*., 2005). In Africa, mineral fertilizers have been recommended for production of cash crops such as coffee and tea (Sanginga and Woomer, 2009). Misiko *et al*. (2008) highlighted that farmers believe that fertilizers “spoil” the soil in that “the soil gets addicted to the fertilizer” so much that if it (the soil) is not fertilized, crop (maize) yields drop drastically. In regard to this mineral fertilizers should only be used upon a foundation of good agronomic methods and ecological principles. It is also important to consider the training and knowledge aspects in the use of fertilizers to achieve sustainable agriculture benefits. The study aimed to evaluate the effect of zai pits in combination with inorganic fertilizer in production of sorghum.

2.2.4 Integrated organic and inorganic fertilizers

Application of combined organic manures with mineral fertilizers offers potential for improving soil fertility and crop yields (Vanlauwe *et al*., 2002). Organic manure and inorganic fertilizer are the most common materials applied in agricultural management to improve soil quality and crop productivity (Verma and Sharma, 2007). According to Ghosh *et al.* (2006) imbalanced nutrient application coupled with low N and P content represent the major constraints that limit crop productivity in many soils. The continuous use of inorganic fertilizers has been associated with an increased soil acidity, nutrient imbalances and soil degradations (Ayoola and Makinde, 2008). Application of organic manure alone to sustain cropping has been reported to be inadequate due to their relatively low nutrient contents and their inability to provide a sufficient amount of nutrients (Ayoola and Makinde, 2008). Integrated nutrient management approaches (Integrated Soil Fertility Management or ISFM), in which both organic manure and inorganic fertilizers are used, have been suggested as an efficient approach for crop production (Ghosh *et al*., 2006). In ISFM nutrients from the organic manures are supplemented with inorganic nutrients that are readily available to plants (Ghosh *et al*., 2006).

Many studies have shown that balanced application of inorganic fertilizers or organic manure plus inorganic fertilizers can increase soil organic carbon and maintain soil productivity (Ngetich *et al*., 2011). Bayu *et al*. (2005) also reported the possibility of saving up to 50% of the recommended NP fertilizers due to amendment with 5-15 t ha^{-1} FYM to sorghum crop without significantly affecting the optimum possible yield that can be obtained with the application of full dose of inorganic NP fertilizers alone. Joy *et al*. (2005) reported the possibility of substituting up to 25% inorganic fertilizers with the application of 30 t ha^{-1} FYM while still maintaining the highest rhizome yield and quality of black musli.

Negassa *et al*. (2001) have shown improved grain yield in maize due to integrated use of FYM and inorganic NP fertilizers. Balemi (2012) similarly reported that yield was significantly influenced by the FYM + NP fertilizers treatments. Bayu *et al*. (2005) and Makinde and Ayoola (2010) stated that high and sustainable crop yields are only possible with integrated use of mineral fertilizers with OM. Rasheed *et al*. (2004) also found that the maximum grain yield of maize was obtained from plots fertilized with 150 kg N ha^{-1} and 15 kg S ha^{-1}. Bado *et al*. (2006) found that high yields were achieved by simultaneous application of organic and mineral fertilizers. Thus, it was pertinent to undertake the study in order to assess how combined organics and inorganics fertilizers influence sorghum production under zai soil water conservation technique in the study area.

2.3 Factors that influence the adoption of zai pits

Adoption and utilization of water harvesting techniques is an important prerequisite for agricultural development particulary in the arid and semi-arid areas. Water harvesting techniques are essential for concentration, collection and storage of rainwater and surface runoff for crop productivity. However, despite the many technologies developed on station and tested on farm by the National Agricultural Research System (NARS) to mitigate the effects of water scarcity in semiarid areas, wide scale adoption at farm level remains low and the productivity continues to be low (Nyamadzawo *et al.*, 2013). Factors influencing adoption of zai pits vary from place to place and from household to household due to variations in socio-cultural, economic and biophysical conditions (Amsalu and de Graaff, 2007). These factors often contradict one another in different studies (Kessler, 2006), as farmers across borders and regions experience varying environmental and socio-economic conditions (Kessler, 2006; Giller *et al*., 2009; Kassie *et al*., 2010). Slingerland and Stork (2000) examined determinants of practice of zai and mulching in north Burkina Faso. They found that farmers applying zai pits had larger households, more means of transport and more livestock, which is consistent with their need for manpower and manure.

In Tillaberi, Niger, Wildemeersch *et al*. (2015) identified that, lack of enough knowledge on erosion and other key resources such as manure, agricultural equipment and transport facilities limit the application of zai. In northern Burkina Faso, Sidibe (2005) found that, variables such as education and perceptions of soil degradation were determinants for the adoption of zai technique. A study by Ndah *et al*. (2014) showed that the high potential adoption of zai pits exhibited by the Malawi and Zambia case relate mostly to positive institutional factors such as well-structured extension system (Nyanga, 2012) and integration of the lead farmer approach (Haggblade and Tembo, 2003). These studies focus on farmers' characteristics and resource availability to explain adoption problems in different regions. However, in Kenya research related to factors influencing farmers' adoption of zai pits is scanty. Therefore it is not sufficient to infer these results for sub-humid and drier regions of Kenya. Moreover, zai pits have their own unique characteristics and requirements different from other rain water harvesting technologies hence it is important to establish factors that influence its adoption.

2.4 Effects of zai pits on soil moisture

Water harvesting and storage is vital to ensure water availability for plant growth especially during the dry spells and drought periods in the semi arid areas. Zai pits increase the amount of water stored in the soil profile by trapping or holding rainwater where it falls (Stott *et al*., 2001). Water stored in the zai delay the onset and occurrence of severe water stress thereby buffering the crop against damage caused by water deficits during dry periods (Nyamadzawo *et al*., 2013). In addition zai captures rainfall and run-off water, increasing water availability to the plant and reducing the negative impacts of erratic rainfall and periodic dry spells (Reij *et al*., 2009). Besides enhancing water storage, zai pits increases water infiltration and reduces run-off for plant uptake during the dry periods (Dreshel *et al*., 2005). Zai can collect up to 25% or more of a run-off coming from 5 times its area (Malesu *et al*., 2006). Zai pits are known to allow crops to regularly succeed in places with high risk of crop failure (Critchley and Gowing, 2012). The current study aimed at assessing the effect of zai pits on moisture retention using organic and inorganic inputs in drought prone areas.

2.5 Impact of zai pits on yields

Research has shown that the zai technology increases crop yield and straw (residue) production on highly degraded soils and helps to alleviate the adverse effects of dry spells, which are frequent during the cropping period in the dry land areas (Kabore and Reij , 2004; Fatondji *et al*., 2006). A report by Kabore and Reij (2004) found that zai increased sorghum yields by 310 kg ha^{-1} compared to the non-zai situation in the village of Donsin, which had adopted this zai pits. In Niger's Illela district, yields in pits were measured on the same farmer-managed fields during a period of 6 years (1991 – 1996). Average cereal yields on untreated fields were 125 kg ha^{-1} and in pitted fields 513 kg ha^{-1}, with a minimum of 297 kg ha^{-1} for 1992 and a maximum of 969 kg ha^{-1} for 1994 (Kabore and Reij, 2004). Zai pits technology (also known as Tumbukiza) produced significantly higher dry matter yields than conventional method in Western Kenya (Muyekho *et al*., 2000).

In semi-arid areas, a drought can lead to total crop failure but experience from Zambia (Haggblade and Tembo, 2003) shows that, planting basins can improve the possibility of maintaining some production with very low rainfall. During an impact assessment of soil water conservation (SWC), agroforestry and agricultural intensification in 5 villages on the northern part of the Central Plateau of Zambia, farmers agreed unanimously that soil water conservation(SWC) and in particular zai had a positive impact on household food security (Reij *et al*., 2001). In West Africa, Bationo *et al.*(2006) found that, the use of zai alone would not not improve much the productivity (only 200 kg ha^{-1} of sorghum grain) but when the zai is associated with manure and fertilizer large crop yield increases can be obtained (1700 kg ha^{-1} of sorghum grain). Again in Niger manure application with zai showed a 2–69 times better grain yields than zai pit with no nutrient amendment (Fatondji *et al*., 2006).

The objective of the study was to evaluate the effect of zai pits on sorghum yields.

2.6 Economic benefits of zai pits

Farmer's decision to adopt a new technology is largely determined on balancing the economic benefits against the economic costs. The technology will be adopted if its expected yields are high enough to compensate for any higher risk it offers relative to current technology (Sin, 2012). In particular, when there is an irreversible cost of adopting, there is an option value to waiting to adopt. This option value means adoption may not occur until the expected benefits are substantially larger than the costs. Given the high labour investment in many conservation farming technologies (Bationo *et al*., 2007) compared to conventional methods, it is imperative to examine the financial returns against the higher labor inputs required to achieve them. Zai pit is a labour intensive technology (Kalungu *et al*., 2014). According to Kabore and Reij (2004), it takes 450 hours ha^{-1} to dig the holes, and another 250 hours ha^{-1} to incorporate fertilizers. Annual maintenance of the pits is estimated at 15-20 days per hectare (Mutunga *et al*., 2001). Nonetheless, the benefits of digging zai pits are considered to be 'very positive' compared with the costs by the farmer (Mutunga *et al*., 2001).

Hatibu *et al*. (2006) found that in Tanzania water harvesting increased the economic returns to both land and labour, as water harvesting allowed farmers to grow rice and vegetables—commodities with greater economic value than the traditional crops of maize and sorghum. Jensen *et al.* (2003) found similar results for maize and maize-cowpea intercropping in that water harvesting provided more income for both market-oriented and subsistence-oriented households though the market oriented households receive larger gross margins. Senkondo *et al.* (2004) found water harvesting allowed Tanzanian farmers to produce rice and onion which was not feasible without water harvesting, allowing for a higher gross margin and return to labour.

An enterprise budget analysis by Mazvimavi and Twomlow (2008) proved that because of the significant yield gains realized with the planting basins, the technology is more viable than conventional tillage practices of broadcasting manure and overall spring tillage on the day of planting. In Mali, the economic return to the farmers' investment was 100%, because the land brought under production was abandoned or unused land (IFAP, 2005). However, tacking stock of the existing knowledge on the zai pits, Vohland and Barry (2009) concluded that the zai pit technology has been insufficiently explored scientifically. Despite the voluminous evidence on yield gains, the evidence on the financial returns to zai pits remains comparatively sparse. This study was undertaken to evaluate the economic feasibility of sorghum production using zai pits under different organic and inorganic amendments.

2.7 Summary and Research Gaps

It is remarkable that different initiatives have coalesced to address the challenge of water scarcity and soil infertility as the main challenges on global food insecurity. Unfortunately adoption and utilization of the recommended technologies is low. However, studies on factors that influence adoption of zai pit as a water harvesting technique in the study area are scanty. It was therefore useful to undertake this study to understand and explain why certain farmers in the low midland zones of Kenya seem to be indifferent on use of zai pits in combination with soil fertility amendments. Moreover, there is limited information on the impact of zai pits on soil fertility parameters such as nutrient replenishment, soil moisture and aggregate stability. It is worthwhile also, to point out that there is still a significant gap on the effect of zai pits in production of sorghum using organic and inorganic inputs in the study area. In particular there is almost no study that has been conducted on the effect of *T. diversifolia* in combination with zai pits in SSA.

Another drawback is that diminutive research has been conducted to assess the economic viability of zai pits in combination with organic and inorganic inputs in production of sorghum. While promoting zai pit technologies as one of the feasible options for improving agricultural productivity in semi- arid environments, there is need to understand the profitability of zai pits in production of sorghum. The study therefore embarked on assessing factors that influence adoption of zai pits as well as the effect of zai pits on soil fertility, sorghum yields and its economic feasibility using different soil fertility amendments.

CHAPTER 3

METHODOLOGY

3.1 Description of the Study area

The study was carried out in Tharaka South sub-county, Tharaka-Nithi County, located in Eastern Kenya. Tharaka Nithi County borders Meru County to the North and Northeast, Kitui County to the East and Southeast and Embu County to the South and Southwest. It has an area of 1,569.5 km^2, population of 175,905 people (KNBS, 2010). Tharaka Nthi County is sub-divided into Tharaka North, Maara, Meru South and Tharaka South sub Counties (Figure 3.1).

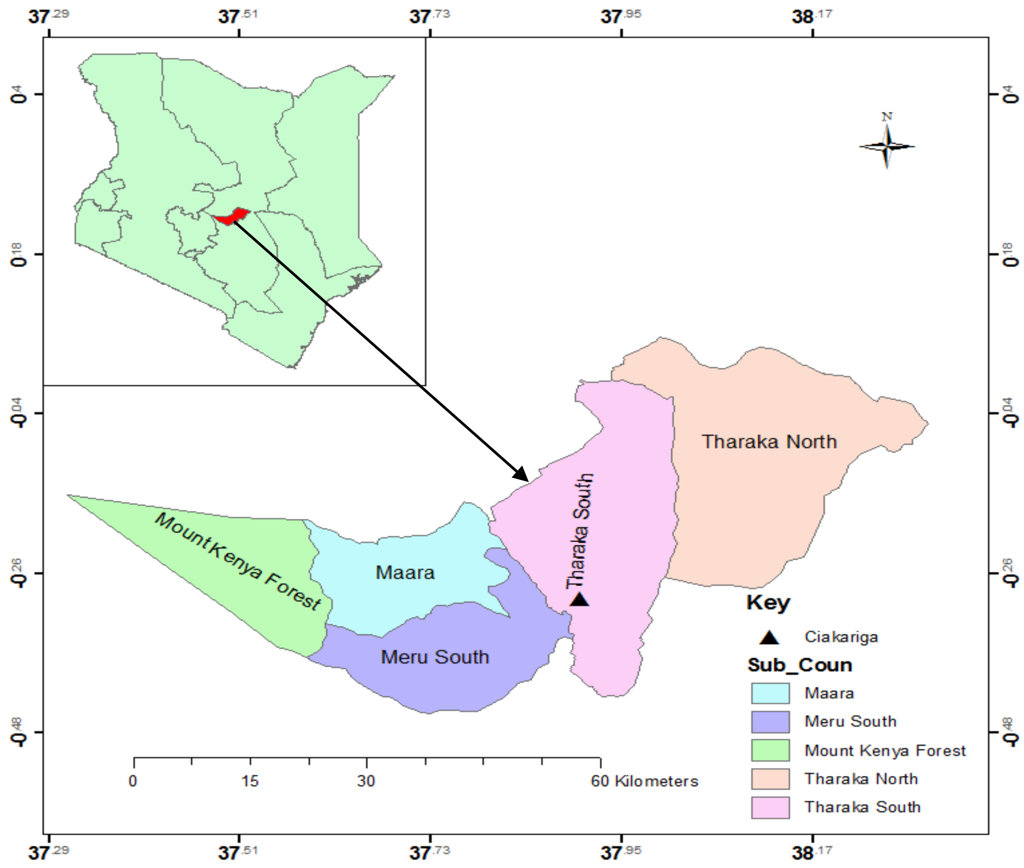

Figure 3.1: Map of the study area Tharaka Nithi County

The agroecological zone of the study area is inner lowland zone (IL5). It has a bimodal rainfall distribution in a year, namely short rains (SR) and long rains (LR) seasons. Annual rainfall in agroecological zone (AEZ) IL5 is 500–750 mm and mean annual temperatures 24°C, respectively (Smucker and Wisner, 2008; Jaetzold *et al*., 2006). Inner lowland zone (IL5) has a very uncertain first cropping season and the second season is very short (Jaetzold *et al*., 2006). Rainfed agriculture is not economical without the use of runoff-catching techniques. Although the rainfall is bimodal it is mostly inadequate to meet crop requirements. The predominant soils in the study area are ferrasols which are highly weathered and leached (Jaetzold *et al*., 2006). The soil in the experiment site are considered infertile as they are deficient in nitrogen (N) phosphorus (P) and zinc (Zn) (Table 3.1).

Table 3.1: Soil chemical characteristics (0–15 cm) at Ciakariga cite, Tharaka Nithi County, Kenya

Soil parameters	**Values**
Soil pH(H_2o)	6.06
Total Nitrogen (%)	0.16
Total Organic Carbon (%)	1.54
Phosphorous (ppm)	23.33
Potassium (me%)	0.67
Calcium (me%)	2.53
Magnesium (me%)	7.79
Manganese (me%)	0.23
Copper (ppm)	3.06
Iron (ppm)	15.97
Zinc (ppm)	3.38
Sodium (me%)	0.08

The main source of livelihood for the Tharaka people revolves around marginal farming and livestock rearing which are greatly affected by long spells of drought, which at times lead to total crop failure and massive loss of livestock (Jaetzold *et al*., 2006). The major crops grown are common bean (*Phaseolus vulgaris),* cassava (*Manihot esculenta),* maize(*Zea mays*), cowpea (*Vigna unguiculata),* green gram

(*Phaseolus aureus)* mango (*Mangifera indica*), common millet (*Panicum* spp), pawpaw (*Carica papaya),* pigeon pea (*Cajanus cajan),* bulrush millet (*Pennisetum typhoideum*), sorghum (*Sorghum* spp.) and finger millet, (*Eleusine coracana)* (Smucker and Wisner, 2008). Although farmers grow maize in this subzone, it is not a suitable crop (Jaetzold *et al*., 2006).

Due to dependence on unreliable and unpredictable means of livelihood, poverty is widespread standing at about 65% (Jaetzold *et al*., 2006). This has led to emigration of the youth in search of food and employment elsewhere leaving behind mostly children, the old, weak and women. Consequently, the overall development of the district has been negatively affected as most of the emigrants are the active labour force. The distribution of relief food and school-feeding programme, are some of the indicators of the extent of poverty (Jaetzold *et al*., 2006).

3.2 Research design

Triangulation approach (O’ Donoghue and Punch, 2003) was adopted for this study. Adoption study related data was obtained through a survey while field experimental approach was used for the evaluation of zai pits and soil fertility technologies effects on Sorghum.

3.3 Objective 1: Factors influencing adoption of zai pit system and organic / inorganic amendments in sorghum production

3.3.1 Sampling strategy

Purposive stratified sampling was used in household interviews to ensure that the representative adopters and non-adopters of the technology were sampled within the area of study. Sampling frame consisted of list of households from the area chiefs (provincial administration) of the locations (Table 3.2). Snowballing sampling approach was used to identify farmers who had adopted zai technology in six locations of Tharaka South sub-County while farmers who had not adopted were randomly sampled. The measure of adoption was the actual presence or use of the technology in farmers' fields.

A sample size was calculated using equation 1:

$$S = \frac{Z^2 \times (p) \times (1-p)}{c^2} = \frac{1.96^2 \times 0.5(1-0.5)}{0.05^2} = 291 - - - - - \text{Equation 1}$$

Where:

S=Sample size

Z=Z value (e.g. 1.96 for 95% confidence level)

p=percentage picking a choice, expressed as decimal (0.5)

c= 5 % confidence interval, expressed as decimal (0.05)

Hence, the sample size was 291

Table 3.2: Distribution of household and sample size in the study area by administrative units

Location	**Households**	**Adopters**	**Non Adopters**	**Sample**
Chiakariga	1,324	18	35	53
Gakurungu	1,331	20	34	54
Kamanyaki	572	10	13	23
Kamarandi	788	15	17	32
Nkarini	1,145	27	19	46
Tunyai	2,068	50	33	83
Total	7,228	140	151	291

3.3.2 Data collection

A structured interview schedule was administered to all selected household heads to gather information on household demographic characteristics, water harvesting techniques and soil fertility related issues.

3.3.3 Pre-testing

A pilot study was conducted to test the suitability of the farmers' interview schedule. A sample of 6 adopters and 6 non-adopters were randomly selected and interviewed. This was conducted in order to check for content and criterion validity of the farmers' interview schedule. It also helped to ascertain the amount of time needed to administer the tools. Those respondents who participated in the pre-test exercise were excluded in the actual survey.

3.4 Objective 2: The effects of zai pits and organic / inorganic amendments on soil moisture content, soil pH organic matter and total nitrogen content

3.4.1 Experimental layout and management

The field experimental layout and management was set to respond to Objectives 2, 3 and 4, to evaluate the effects of zai pits in combination with selected ISFM technologies on yields, soil fertility and its economic feasibility on sorghum production. The experiment was laid in a randomized complete block design (RCBD) in a farmer's field (S 00 13'46.1 E 037 51'51.5", elevation 816 m) in Tharaka sub-County. The field experiment was carried out during the short rains 2013 (SR13), Long rain 2014 (LR14) and short rain 2014 (SR14) seasons using treatments shown in Table 3.3. The test crop was sorghum Gadam variety. Plot dimensions were 4.5 m x 6 m. Three seeds were planted per hill at a spacing of 0.75 m by 0.2 m, inter- and intra-row, respectively and thinned two weeks after emergence to two plants per hill in conventional planting. For zai pits, the holes were dug at a spacing of 0.75 and 0.6 m as inter- and intra-row, respectively. Five hills (four near each corner of the pit and one at the centre) were made in every zai pit and three seeds were sown per hill and thinned two weeks after emergence to two plants. External nutrient amendments were applied to give an equivalent amount of 60 kg N ha^{-1}(FURP, 1987) with different amendments.

Table 3.3: Experimental treatments during the SR13, LR14 and SR14 in Ciakariga, Tharaka-Nithi County

Treatment No.	Technique	Organics or Inorganics	Treatment combination
1	Zai pits	cattle manure	ZC
2	Zai pits	Tithonia diversifolia	ZT
3	Zai pits	Mineral fertilizer 60 kg N ha^{-1}	ZF60
4	Zai pits	Cattle manure + 30 kg N ha^{-1}	ZC30
5	Zai pits	Tithonia + 30 kg N ha^{-1}	ZT30
6	Zai pits	No inputs	ZNO
7	Conventional	cattle manure	CCM
8	Conventional	Tithonia diversifolia	CT
9	Conventional	Mineral fertilizer 60 kg N ha^{-1}	CF60
10	Conventional	Cattle manure + 30 kg N ha^{-1}	CC30
11	Conventional	Tithonia + 30 kg N ha^{-1}	CT30
12	Conventional	No inputs	CNO

Land preparation was done using hand hoes, fertilizer application was spot applied during planting. Cattle manure was spread and incorporated during ploughing. Inorganic fertilizers (NPK 23:23:0 and Triple Super Phosphate, TSP) were spot applied and thoroughly mixed with soil during planting at a rate of 60 kg N and 90 kg P ha^{-1}. Tithonia was harvested, weighed, chopped and incorporated into the soil at a depth of 15 cm during land preparation. Standard agronomic management practices for sorghum production were appropriately followed after planting.

3.4.2 Data collection

3.4.2.1 Soil moisture

One access tube per plot was inserted manually in the middle of every plot during the SR13 for soil water measurement. The polyvinyl chloride (PVC) tubes were 130 cm long and 5 cm in diameter with a watertight lid at the bottom. For the plots with zai pits, the tube was placed inside the middle zai pit. Slurry method of re-filling was used to facilitate and hasten intimate contact between the tubes and the soil. Slurry is made using fine soil (<2 mm diameter) and water (Evett, 2008). The slurry is poured into the bottom of the hole and the access tube is implanted, displacing the slurry and pushing the slurry to move upward in the hole, forcing out air and filling voids between the access tube and hole wall (Evett, 2008). A protrusion of 30 cm above the soil surface was left for covering and to prevent runoff entry into the tubes. Soil moisture content was determined using a capacitance probe (PR-2 probes from Delta-T Devices Ltd., UK) fortnightly at 5, 15, 25 and 35 cm depth during the cropping season (Evett, 2008).

3.4.2.2 Soil samples

The initial sampling was done beginning of SR13 before establishment of the experiments on three blocks. Five soil samples were collected per block and then bulked to one composite sample to reduce variability. A subsample was then taken for laboratory analysis. The final sampling was done at the end of SR14 at the end of the experiments. Samples were taken following a W shape across the plot using an alderman auger. The soil samples were packed in plastic bags with marked tags. In the laboratory, each sample was given a laboratory number. They were then put in a freezer to minimize microbial activity and later on dried in an air-forced oven at

30^0C. When dry the soil samples were then cleaned off stones and plant residues. Samples were then ground in a stainless steel soil grinder and passed through a 2-mm sieve.

3.4.3 Laboratory Analyses

All laboratory analyses (both physical and chemical) were done following the standard methods of soil analysis as described by Ryan *et al.* (2001) at National Agricultural Research Laboratories in Nairobi (NARL), Kenya.

3.4.3.1 Soil pH

Soil pH was determined with a pH meter at a 1:1 (w/w) soil/water ratio. Fifty grams of air dried soil was added to 50ml distilled water in a 100 ml glass beaker and.The solution was then stired for 10 minutes and then let to stand for 20 minutes. The sample was then stirred for five seconds with a glass rod just before measuring the pH. The soil was allowed to settle for 30 seconds and the the electrode immersed into the 100 ml glass beaker with the mixture and pH reading was recorded after it stabilized. The electrode was then removed from the bottle and rinsed with distilled water. All the samples were treated the same way.

3.4.3.2 Total Nitrogen

Nitrogen in soil was determined using kjeldahl method. About 0.5g of dry soil sample ground to pass through 0.3mm mesh was weighed into labeled digestion tubes and 1.8gK_2SO_4 added. Soil samples (< 0.5 mm) were digested with soil digestion mixture potassium sulphate, selenium and copper sulphate hydrated and left to stand overnight. The contents were heated at 100^0 for 2 hours after which they were thoroughly mixed. The tubes were stoppered and let to stand so that a clear solution could be taken for analysis. The samples were read on the atomic adsorption spectrophotometer at 65nm. The total N was then calculated using formula in Appendix 2

3.4.3.3 Organic Carbon

Organic carbon was determined using modified Walkley and Black wet oxidation method described by Ryan *et al.* (2001). One gram of air dried soil passed through 0.5 mm sieve were weighed into 500 ml wide mouth beaker and 10 ml of 1 N potassium dichromate added into the flasks using a burette. In a fume cupboard, 15 ml concentrated sulphuric acid was rapidly added directing the stream into the suspension. The flasks were swirled gently at first until all soil and reagents mixed and then more vigorously for about one minute. They were then allowed to stand for exactly 30 minutes. About 200 ml of distilled water was added and allowed to cool, after which 10 ml 85% orthophosphoric acid and finally 10 drops diphenylamine indicator were added. The solutions were titrated with 0.5 N ammonium ferrous sulphate solution. Organic carbon was calculated using formula in appendix 2

3.4.3.4 Phosphorous

Extractable Phosphorus for soils with pH 7.0 and above was determined using Olsen method (Olsen *et al.*, 1954) while Mehlich was used for soils with pH below 7. Soil samples were oven dried at 40^{o}C. In the digestion chamber, 2 g air-dry soil (0.15 mm) was weighed into a 250 ml calibrated digestion tube, 30 ml 60% perchloric acid and a few pumice-boiling granules were added and mixed well. Tubes rack was placed in the block-digester and gently heated to about 100°C. Block-digester temperature was slowly increased to 180°C and the samples digested until dense white fumes of acid appeared. An extra perchloric acid was used to wash down the sides of the digestion tube as necessary. Heating continued at the boiling temperature for 15 minutes longer. At this stage the insoluble material became like white sand. The total digestion with perchloric acid required about 40 minutes.

The mixture was cooled and distilled water added to obtain a volume of 250 ml, contents mixed and filtered through Whatman No. 1 filter paper. About 5 ml of the sample digest was pipetted into a 50 ml volumetric flask, 10 ml ammonium-vanadomolybdate reagent added, and diluted to volume with DI water. A standard curve was then prepared by pipetting 5 ml (2 – 10 ppm) and preceded as for the samples. A blank was made with 10 ml ammonium-vanadomolybdate reagent, and preceded as for the samples. Absorbance of blank, standards, and samples were read after 10 minutes. A calibration curve was prepared for standards, plotting absorbance against the respective P concentrations. P concentration was read in the unknown samples from the calibration curve and calculated using formular in Appendix 2.

3.4.3.5 Potassium, Sodium, Calcium, Magnesium and Manganese

Chemical analysis of K, Na, Ca, Mg and Mn was done using Mehlich Double Acid method (Mehlich, 1984). After the soil samples were oven dried at 40^0 C, soil samples (< 2 mm) were extracted in a 1:5 ratio (w/v) with a mixture of 0.1 N HCl and 0.025 N H_2SO_4 then filtered with what man No.5 fiter paper into clean 60 mL bottles. Sodium Calcium and Potassium were determined with a flame photometer and Mg, Cu, Zn, and Mn, were determined spectrophotometrically.

3.4.3.6 Aggregate stability determination

Aggregate stability was determined using dry-sieving method described by Gartzia-Bengoetxea *et al.* (2009). The field-moist soils were dried at 40^oC for 24 hours.

After air drying, the three soil samples per plot were subsequently passed through an 8 mm sieve to remove coarse plant residues, roots and any stones >8 mm. Fifty grams of dry soil aggregates were placed on a set of six nested sieves of 2 mm, 1 mm, 0.5 mm, 0.25 mm, 0.15 mm and 0.075 mm. The sieves were mechanically shaken (amplitude 1.5 mm) for 2 min to separate the soil into the following aggregate size classes: >2.0 mm (large macro aggregates);2.0 – 1 mm (macro aggregates); 1 – 0.25 mm (small macro-aggregates); and <0.25 mm (micro aggregates and silt and clay fractions) (Briar *et al.*, 2011). The fractionated samples were combined to make composite samples for each aggregate size class. The mean weight diameter was calculated using equation 2

$$MWD = \sum_{i=1}^{7} \bar{x}_i w_i$$

---------- Equation 2

Where:

MWD = mean weight diameter (mm)

x = mean diameter of each size fraction size *i* (mm)

w = proportion of total sample weight (g) size fraction *i*

7 = number of size fractions

3.5 Objective 3: Effects of zai pits in combination with selected organic / inorganic amendments on sorghum yields

3.5.1 Data collection

The field experiment outlined in section 3.4 was used to collect data on grain yield and stover yield. Sorghum grain and stover were harvested at maturity from a net area of 27 m^2 on conventional treatment and from 18 pits on zai pit treatment. The edge effect had been minimized by the guard rows that had been planted in between the plots. Various routine observations were made in the course of each season which included: daily rainfall, time of germination, flowering maturity and drying, plant population at harvest, grain and biomass yields. The sorghum grain heads were manually separated from the stover, sun-dried and hand threshed. After threshing, moisture content of the grains was determined using a moisture meter and grain weights adjusted to 12.5% moisture content. Sorghum grains were dried and expressed in terms of dry matter content. Above ground biomass yields were determined on dry weight basis after harvesting and sun drying until constant weight.

3.6 Objective 4: Evaluation of economic returns of zai pits utilization in combination with organic / inorganic amendments on sorghum production

3.6.1 Data collection

To determine economic feasibility of sorghum production using the different treatments various variables were evaluated. The variables were: cost of the seeds and inputs; labour costs (in land preparation, planting, weeding, harvesting and spraying); quantities of sorghum grain harvested and their value; quantities of sorghum biomass harvested and their value (Table 3.4).To calculate the benefits, harvested yields for grains and stovers for each treatment were reduced by 10% to adjust to realistic values if the experiment was to be managed by the farmer (CIMMYT, 1988).

Table 3.4: Parameters used to calculate the economic returns of sorghum production during the SR13, LR14 and SR14 in Ciakariga, Tharaka-Nithi County

Parameter	Actual values (US\$ kg^{-1})
Price of NPK-3400Kg	37.7
1 kg N	1.63

Labour cost 8 hours	0.28
Price of 1 kg sorghum grain	0.31 for SR13, 0.32 for LR13 and SR14
Price of 1Kg sorghum stover	0.026

Exchange rate KES 90 = 1 US$ (January, 2015)

3.7 Data Management and Statistical Analysis

The first stage of data handling involved data cleaning. The questionnaires were examined to ensure they were complete and had been consistently filled in. Household survey data was analysed using Statistical Packages for Social Sciences (SPSS) software (Version 16). Descriptive statistics such frequencies, mean, standard deviation and cross tabulations were used to summarize the data. Chi-square analysis was undertaken to test the association between farmers' socio-economic characteristic and adoption of zai pits. To determine whether existing differences of means between adopters and non-adopters were statistically significant paired t- tests was used. Binary logistic regression was used in zai pit adoption model to determine factors influencing adoption of zai pits using equation 3.

$\text{Log } (P/1\text{-}P) = a + \beta_1 x_1 + \beta_2 x_2 + \ldots\ldots + \beta_8 x_8 + e \ldots 1$ -----Equation 3

Where

P is the probability of adopting zai pits

(1-P) is the probability that a farmer does not adopt zai pit

a= y intercept

β = régression coefficients

e= error term

X_1-X_{11}= independent variables (…………)

Independent variables were the socio–economic characteristics as follows;

X1 Non-Formal Trainings (continuous)

X2 Household Size (continuous)

X3 No Groups (continuous)

X4 Land Slopy (0=No, 1=Yes)

X5 Formal Title Deed (0=No, 1=Yes)

X6 Fertility Status (1=high, 2=moderate, 3=Poor)

X7 Wealth Status (1=Rich, 2=Average, 3=poor)

X8 Received Relief (0=No, 1=Yes)

X9 Sell Farm Produce (0=No, 1=Yes)

X10 Improved Planting Material (0=No, 1=Yes)

X11 Total Farm Size (continuous)

Sorghum yield data and soil data were subjected to analysis of variance (ANOVA) using Proc ANOVA procedure in SAS 9.2 software (SAS Institute, 2004) to obtain an F value of the effect of the model. Pair-wise comparison of soil nutrient differences between the start and the end of the experiments was analysed using t-test. Differences between treatment means were examined using least significance difference (LSD) at $p = 0.05$.

The gross margin analysis was be used to estimate economic feasibility of sorghum production under different treatments.

Gross margin model used was as shown in equation 4:

GM=TR-TVC---------------Equation 4

Where:

GM = Gross margin (US$ ha^{-1})

TR = Total revenue or total value of output from the sorghum enterprise (US$ ha^{-1}) both grain and biomass. It is the product of average output per hectare multiplied by the market price.

TVC = Total variable cost or the costs that are specific in producing (sorghum) output ((US$ ha^{-1})). TVC varied according to output and are incurred on variable inputs. This includes cost of inputs like seeds, fertilizer, and harvesting, labour cost (hired which vary as per treatment).

Benefit cost ratio was calculated using equation 5.

BCR=TR/TVC---------------- Equation 5

All the biophysical data were subjected to analysis of variance using the ANOVA Procedure to obtain an F value of the effect of the model for each treatment. Significance of differences between treatments means were examined using Least Significant differences (LSD) at the 5% level of significance.

CHAPTER 4

RESULTS AND DISCUSSIONS

4.1 Overview

This chapter presents the results and discussion of the study according to the respective objectives. Daily rainfall for three seasons, SR13, LR14 and SR14, during which field experiments were carried out has been reported in this chapter. Socio-economic characteristics such as gender, age, level of education, farming experience, extension visits, farm size, cattle ownership among others are discussed in the contexts of their influence on adoption of zai pit system. Interactive effects of zai pits and conventional tillage systems in combination with selected organic/inorganics on soil pH, organic carbon and total nitrogen content is reported. Yield results under different combinations of treatments are also discussed. The chapter ends with discussion of results on economic viability of zai pits and conventional system in combination with selected organic/inorganic inputs on sorghum productivity.

4.1.1 Rainfall distribution during the SR13, LR14 and SR14 in Ciakariga, Tharaka Nithi County

The three growing seasons received varying amounts of rainfall. The total seasonal rainfall recorded during the SR13, LR14 and SR14 growing season was 342.3 mm 249.7 mm and 461 mm, respectively (Figure 4.1). During the LR14 growing season, rainfall was only experienced in 12 days while SR13 and SR14 had 25 and 16 rain days respectively. Out of the 12 rain days of LR14, 9 days had received less than 14 mm rainfall while the others were 20.4 mm, 44 mm and 120 mm, sequentially.

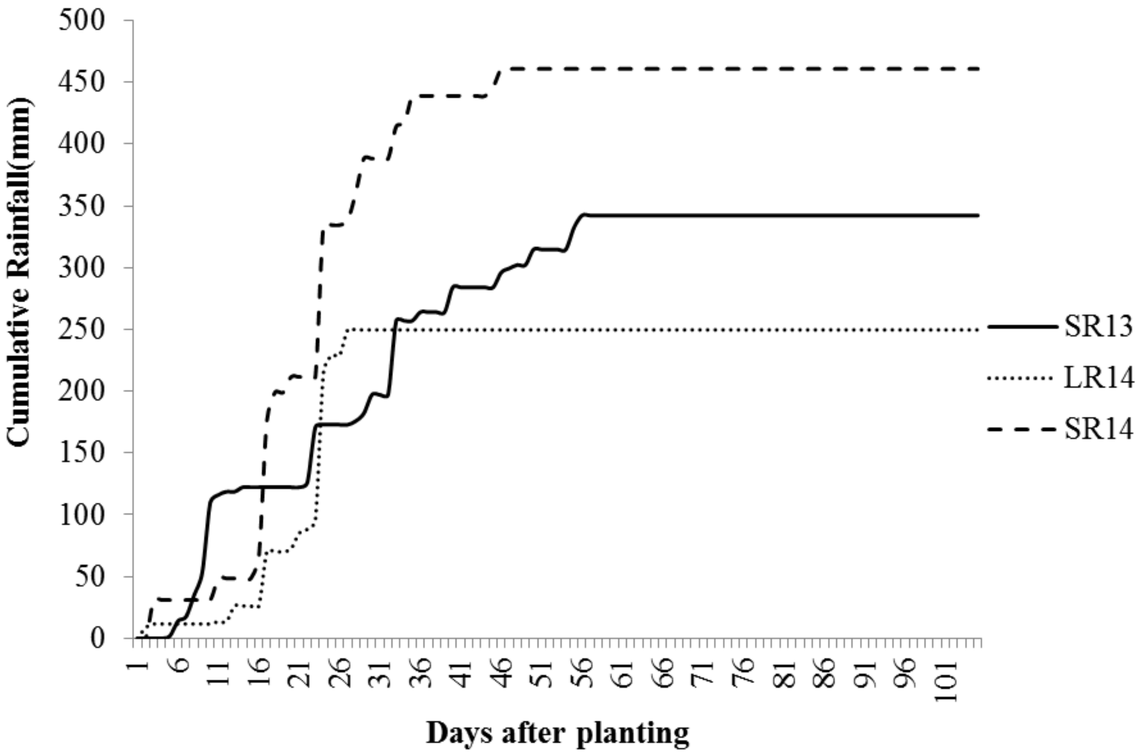

Figure 4.1: Rainfall distribution during the SR13, LR14 and SR14 in Ciakariga, Tharaka Nithi County

The total daily rainfall recorded during the SR13 growing season ranged between 2.6 mm to 60 mm while it ranged between 2 mm and 120 mm for the LR14 and between 2.8 mm and 123 mm during the SR14 growing season. The SR14 growing season recorded the highest rainfall event of 123mm and 110mm on the 24th and 17th day after planting while the highest daily rainfall event for SR13 was on 33rd and 24th after planting for LR14. The sudden high rainfall during the SR14 season was detrimental to the zai pits as it caused flooding (plate 4. 1) for a while but later the water drained.

Plate 4.1: Flooded zai pit in experimental plots in Tharaka Nithi County

Dry spells were experienced after 57th day, 28th day and 46th day after planting during the SR13, LR14 and SR14 growing seasons, respectively. The dry spell coincided with the flowering stage of the sorghum resulting in low production and almost a complete crop failure during LR14 growing season. Dry spells occurring during the cropping period are a characteristic feature of semi-arid areas of East Africa (Barron et al., 2003), West Africa (Graef and Haigis, 2001) and Southern Africa (Usman and Reason, 2004). A study on sorghum (Craufurd and Peacock, 1993) found that grain yields could be reduced by 87% with water stress at the time of stem swelling and flowering. Rainfall recorded during the three seasons also exhibited the poor distribution of rainfall during the growing season which contributes to negative effects of crop yields (McCarl et al. 2008).

The varying total rainfall in different seasons agrees with other observations that populations in Eastern Kenya depends on OND rains which are considered reliable and can be predicted with a reasonable degree of accuracy (Hansen and Indeje, 2004). This is because of the relatively higher rainfall amount recorded during short rains (Amissar-Arthur et al., 2002; Barron et al., 2003) than long rains season. According to Mulat et al. (2004) the amount and temporal distribution of rainfall is generally the single most important determinant of inter annual fluctuations in national crop production levels. Other studies have observed that rainfall is the most important climate parameter which influences growth characteristics of crops (Bewket 2009; Befekadu and Berhanu 2000). Although in some instances there were cases of rains between the growing seasons it was assumed that rainfall during non-growing season months did not have direct impacts. These assumptions are supported by a number of authors (Adams et al, 2003, Schlenker and Roberts, 2009). Therefore, analysis of rainfall impact on such crops as sorghum (Smucker and Wisner, 2008) should be based on long rains and short rains growing seasons and not annual rainfall to avoid the high covariance arising from the dry spell periods during the year. Similar, results were reported by Hansen (2002) who observed that crop production is likely to depend more on the distribution of precipitation within a season but not on total seasonal rainfall.

4.2 Factors influencing adoption of zai pits

4.2.1 Socio-demographic characteristics of adopters and non-adopters of zai pit technology in Tharaka Nithi County

The respondents interviewed composed of 76.6% male farmers and 32.4% female farmers (Table 4.1). About 51.9% of the respondents were non-adopters while 48.1% were adopters. Most (63.8%) of the respondents had attained primary education while about 14.7% had no formal education. Out of the 34 respondents who had attained tertiary education, 22 of them were non-adopters (Table 4.1).A higher percentage (85%) of the farmers was involved in farming as an occupation while only 7% were in business (Table 4.1).

Table 4.1: Social demographic characteristics of adopters and non-adopters of zai pit technology in Tharaka Nithi County

Gender	**Non-Adopters**	**Adopters**	**Total**
Male	115(76.2)	108(77.1)	223(76.6)
Female	36(23.8)	32(22.9)	68(32.4)
Total	*151(100)*	*140(100)*	*291(100)*
Age (years)			
21-40	72(47.7)	48(34.3)	120(41.2)
41-60	53(35.1)	73(52.1)	126(43.3)
61-80	26(17.2)	19(13.6)	45(15.5)
Total	*151(100)*	*140(100)*	*291(100)*
Level of education			
No Formal Education	24(15.9)	19(13.4)	43(14.7)
Primary Education	92(60.9)	94(66.9)	186(63.8)
Secondary Education	13(8.7)	15(11.0)	29(9.8)
Tertiary Education	22 (14.5)	12 (8.7)	34(11.7)
Total	*151(100)*	*140(100)*	*291(100)*
Occupation of household head			
Farming	126(83.2)	122(87.4)	248(85.2)
Business	7(4.7)	9(6.7)	16(5.6)
Employed	18(12.1)	9(5.9)	27(9.2)
Total	*151(100)*	*140(100)*	*291(100)*

Numbers in parentheses are the percentage of respondents. N=291

The number of female adopters was almost equal to number of female non-adopters. Similarly, to the male adopters was almost the same percentage as male non-adopters. Gender difference is known to determine the choice of soil conservation and water harvesting technique (Buyu, 2002). Women base their choices in terms of the opportunity cost of realizing better yields while men consider cost related matters such as labor and time requirements (Buyu, 2002). Although it has been observed that female farmers are less likely to adopt zai pit technologies since they are labour intensive, the proportion of female adopters (22.9%) in this study was almost equal to that of female non-adopters (23.8%).This is probably because female famers are equally committed as male farmers to find mitigation measures to food insecurity and overall improvement of their families' wellbeing.

A higher percentage of middle aged farmers (41-60 years) had adopted zai pits compared to older farmers (61-80 years) and young farmers (21-40 years). This could be attributed to the fact that, Zai pit technique is labor intensive. It may also be pointed out that middle aged farmers may have good understanding and experience of their environment and the benefits of the respective techniques compared to young farmers. According to a study by Lapar and Pandey (1999) the age of the farmer is a significant factor that can affect use of soil conservation technologies. This attributed to the fact that younger farmers may be less interested with food security matters while the middle aged farmers could be more aware of the benefits of water harvesting technologies through experience. In addition older farmers may be more conservative, less flexible and more uncertain about the benefits of zai pits.

Education levels of the farmers may influence chances of implementing and/or adopting the water harvesting techniques. Low education levels of the interviewed respondents may have significantly contributed to the low or non-adoption of water harvesting techniques. This is because, education increases one access to information and therefore creates awareness and contributes to adoption of water harvesting systems. Chianu and Tsujii (2004) reported that farmers' educational achievement can increase the probability of water harvesting technology adoption.

Majority of farmers (85.2%) depended on farming activities for survival and generation of income. According to Kirsten and Moldenhauer (2006), agricultural activity is one of the many possible sources of employment and income for farm households across the world. This perhaps may be one of the reasons why adoption of the water harvesting technologies is low. Construction of zai pit has been observed to be labourious and expensive for farmers without adequate family labour (Kabore and Reij, 2004). Hence, income from farming alone may not be enough to implement the technology in addition to the other competing uses such as health, education, and nutrition among others.

4.2.2 Dummy explanatory variables that affect adoption of zai pits by Farmers in Tharaka Nithi County

Majority (60%) of the farmers interviewed had attained 1 to 5 times non- formal trainings on agricultural practices. There was a significant relationship (χ^2=31.3, p=0.001) between attendance of non-formal trainings and adoption, where a higher percentage of those who had attended more than 10 trainings were adopters (Table 4.2). The results from cross tabulations showed that membership in groups and associations had a significant relationship with adoption (χ^2=31.339, p=0.005). On the other hand, 37% of the non-adopters had never attended any non- formal training which is an indication that non-formal trainings have a significant influence on adoption of zai pits in the region. Also the external support given to the farmers by the NGOs had a significant and positive (χ^2=23.285, p=0.005) effect on the adoption of zai since a higher percentage of the adopters were beneficiaries compared to non-adopters. There was a positive significant relationship between adoption and landscape of the land (χ^2=7.912, p=0.003) where a higher percentage (64.7%) of the farmers who were adopters reported that their land was sloppy (Table 4.2). The χ^2 analysis showed a significant association between visits by non-government extension and adoption (χ^2=6.02, p=0.05) (Table 4.2).

Table 4.2: Explanatory variables that affected adoption of zai pits by Farmers in Tharaka Nithi County

Variables	Adoption		Total	Chi-Square Tests
Non -Formal trainings	Non-Adopters	Adopters	**Total**	
None	55(36.7)	22(15.9)	77(26.7)	χ^2=31.339 , df=3, P=0.001)
1--5 times	87(58.0)	86(62.30	173(60.1)	
6-10 times	8(5.3)	14(10.1)	22(7.6)	
More than 10 times	0(0)	16(11.6)	16(5.6)	
Total	*150(100)*	*138(100)*	*288(100)*	
Member of Association/ farmer group				
No	28(18.7)	10(7.1)	38(13.1)	χ^2=31.339 df=1 p=0.005
Yes	122(81.3)	130(92.9)	252(86.9)	
Total	150(100.0)	140(100)	290(100)	
Beneficiary of NGO				
No	75(49.7	31(22.6	106(36.8)	χ^2=23.285 df=1, p=0.001
Yes	76(50.3)	106(77.3)	182(63.2)	
Total	*151(100)*	*137(100)*	*288(100)*	
Land sloppy				
No	78(51.70)	49(35.3)	127(43.8)	
Yes	73(48.3)	90(64.7)	163(56.2)	
Total	*151(100)*	*139(100)*	*290(100)*	χ^2=7.912 df=1, p=0.003
Visited NGO Worker				
No	137(54.8)	113(45.2)	250(100)	
Yes	14(34.14)	27(65.85)	41(100)	χ^2=6.02
Total	151(51.9)	140(48.1)	291(100)	df=1, p=0.05

Numbers in parentheses are the percentage of respondents. N=291

The results suggest that non formal training plays an important role in the uptake of zai pit technology. Similar studies denoted significant and positive association between training and adoption of water harvesting technologies (Kihara, 2002). At the same time, most adopters belonged to farmers association or groups. The rationale is that a farmer belonging to an association or a group is most likely able to access information from other farmers in the group on benefits of zai pits.

Most of the farmers who were adopters had benefited from NGOs. Non-governmental organizations such as Catholic Diocess of Meru have been promoting water harvesting techniques in Tharaka Nithi using 'cash for asset model' and hence the reason as to why more adopters had benefited from the NGOs. Elsewhere in Malawi, International Maize and Wheat improvement Center (Centre International de Mejoramiento de Maizy Trigo) (CIMMYT) and Total Land Care (TLC) with other national and international bodies are responsible for the positive uptake of conservation agriculture adoption (Mloza-Banda and Nanthambwe, 2010). In Zambia Conservation Agriculture Unit (CFU), Golden valley Agricultural Research Trust (GART) and other supporting organizations are accountable for adoption of water harvesting technologies (Nyanga, 2012). This implies that promotion by external organizations plays a significant role in adoption of soil water management technologies.

Based on the results of the study, majority of the adopters reported that their land was sloppy. This could be attributed to the fact that, zai pits are associated with collection of runoff (Nyamadzawo, 2013). Hence most farmers may have adopted the technology as a soil erosion control measure. Majority of the adopters indicated that they had been visited by NGO workers. This implies farmers were able to access information on zai pits from the NGO workers. This is in line with research finding by Melaku (2005) who found a positive and significant association of extension service and adoption of rain water harvesting technology. In a study by Marsh *et al.* (2000), extension as a source of information was shown to influence adoption of agricultural technologies. This is because farmers gain information about improved technologies through extension visits and are, therefore, able to make informed decisions.

4.2.3 Continuous variables that affected adoption of zai pits in Tharaka Nithi County

The average age of the adopters was 46.3 years while that of the non-adopters was 44.7 years. The result of the t-test showed a significant difference (*p*=0.007) between house hold size of adopters (6.06) and non-adopters (5.34) (Table 4. 3). In addition there was also significant difference (*p*=0.007) of household members working on the farm among adopters and non-adopters (Table 4. 3).

Table 4.3:Continuous variables that affected adoption of zai pits by Farmers in Tharaka Nithi County

	Adoption	**N**	**Mean**	**Std Deviation**	**t**	**df**	**Sig. 2tailed**
Age HH	Non-Adopters	151	44.8	14.51	0.964	276.6	0.336
	Adopters	140	46.3	12.07			
Years Farming Experience	Non-Adopters	151	20.2	12.62	1.514	282.1	0.131
	Adopters	140	22.	13.33			
HouseholdSize	Non-Adopters	151	5.3	2.08	-2.707	268.5	0.007
	Adopters	140	6.1	2.38			
House Members Working	Non-Adopters	151	3.0	1.68	-2.709	258.5	0.007
	Adopters	140	3.6	1.81			
Number of Groups	Non-Adopters	151	1.7	1.10	-4.835	259.7	0.001
	Adopters	140	2.4	1.34			
Total Farm Size	Non-Adopters	151	5.5	5.39	-2.237	284.0	0.026
	Adopters	140	6.8	4.83			
Cattle	Non-Adopters	151	1.4	1.69	-2.594	255.9	0.01
	Adopters	140	1.1	2.27			
Goats	Non-Adopters	151	4.1	6.07	-2.262	286.2	0.024
	Adopters	140	5.7	6.22			

The number of groups a farmer belonged also influenced the adoption of zai pits. A significant difference existed between the adopters and the non-adopters at less than

1% probability level (Table 4. 3). The implication is that majority of the adopters had joined many groups as compared to their counterparts. The average total farm size for the adopters was higher (6.81acres) than for non-adopters (5.45 acres), hence a significant difference exists at less than 5% probability level (Table 4.3). There was a significant difference at (P=0.01) on ownership of cattle as the average number of cows owned by adopters (2.3) was higher compared to the non-adopters (1.7) (Table 4. 3). At the same time a significant difference was experienced on the number of goats owned by the adopters (5.67) and the non-adopters (4.04) at less than 5% probability level (Table 4. 3).

Although the difference in age was not statistically significant other studies indicate that older farmers are used to short term planning thus are more reluctant to invest in soil conservation technologies which take long before realizing the benefits (Tizale, 2007; Marenya and Barreta, 2007). This is in contrast to Doss (2006) findings who reported that older farmers could be more aware of soil infertility in their farms hence are more interested and willing to try new technologies that curb the negative effects. The results also implied that adopters had more labour sources compared to the non- adopters. Large household implies more provision of labour especially in the preparation and maintenancen of water harvesting technologies (Bunclark, 2011). This agrees with research findings of Buyinza *et al.* (2008) that farmers who had bigger farm size were likely to adopt rain water harvesting techniques. The study established that adopters had more livestock resources than non-adopters even though there was no significant difference in ownership of sheep, donkeys and chicken. Livestock are considered as a source of wealth and this adds confidence to farmers as they adopt new technologies. The findings agree with the study of Musaba (2010) who reported positive association between herd size and technology adoption.

4.2.4 Integration of zai pits and soil fertility amendments

Ninety five percent of the farmers who had adopted zai pits used animal manure as a soil fertility amendment (Table 4.4). Only 2.1% of the farmers combined animal manure plus fertilizer as input to zai pits. At least 17.1% of the farmers utilize zai pits in combination with green manure while only 4.3% apply fertilizer in the zai pits. Further, 6.4% reported having not used any input at all on zai pits (Table 4.4). A combination of animal manure and crop residue had also been applied by 27.9% (Table 4. 4).

Table 4.4: Combination of zai pits and soil fertility improvements in Tharaka Nithi County

	Practice Zai and ISFM		Total
Zai Pits +ISFM	No	Yes	
Zai pits +animal manure	7(5)	133(95.0)	140
Zai pits+green manure	116(82.9)	24(17.1)	140
Zai pits + fertilizer	134(95.7)	6(4.3)	140
Zai pits +Animal manure +Fertilizers	137(97.9)	3(2.1)	140
Zai pits +crop residues +Fertilizers	136(97.1)	4(2.9)	140
Zai pits +Animal manure +crop residues	101(72.1)	39(27.9)	140
Zai pits alone	131(93.6)	9(6.4)	140

Number in parenthesis (Percentage)

The study suggests low use of soil fertility amendments except animal manure in combination with zai pits. This could be due to availability of animal manual locally.

According to Liniger *et al.* (2011) combining different soil fertility amendments with soil and water conservation is more suitable. Manure placed in the pits improves plant growth and better use is made of the harvested water (Anschuetz *et al.*, 2003). In Burkina Faso a combination of manure application with zai pits resulted in more than two fold grain yield compared to that without manure (Fatondji *et al.*, 2006). For optimal yields, 3 Mg of manure ha^{-1} or 300 g per zai pit should be applied (Fatondji *et al*., 2006).

Farmers in the study area also reported that they used different sources of manure and applied different amounts of manure ranging from 0.0005 Mg to 0.03 Mg per zai pit. Results indicate that very few farmers applied fertilizer on zai pits. The findings are in line with studies by Morris *et al*. (2007) and Potter *et al.* (2010) who reported that majority of smallholder farmers use no or low rates of fertilizer as low 8 kg ha^{-1} in Africa, compared with 100 kg ha^{-1} application rate in Asia.

4.2.5 Benefits and challenges of zai pits

Farmers perceived zai pits to have various benefits with high economic returns getting the highest rating. Control of soil erosion and improved soil fertility were also regarded as being important (Table 4.5). Less weeds as well as low input application were not considered as major benefits in adoption of zai pits (Table 4.5). The biggest challenge perceived by the farmers was that zai pits are labour intensive followed by difficult in maintenance (Table 4.5). The fact that a farmer cannot use animal traction was equally considered as a major challenge (Table 4.5). However, the absence of immediate benefits was not perceived as a major challenge by most of the farmers.

Table 4.5: Benefits and Challenges of zai pits in Tharaka Nithi County

Benefits of zai pits	**Mean scores**	**Std. Deviation**
High Economic Return	4.7	0.77
Improve Soil Fertility	3.9	0.87
Less Weeds	2.2	0.97
Precise application of inputs	2.4	1.01
Control Soil Erosion	4.0	1.02
Increased water Retention	3.7	1.06
Ease Apllication Pestcide	2.8	1.13
Challenges of Zai pits		
Labour Intensive	4.1	1.25
Difficult to Maintain	3.9	1.14
Requires Skills	3.2	1.02
Occupy Large Portion Land	3.1	1.33
No Immediate Benefits	2.1	1.05
Not Possible To Use AnimalTraction	3.7	1.46
Waterlogging	2.8	1.42

High economic returns could be associated with the increased yields that occur as a subsequence of water retained in the pit despite unreliable rainfall within the region. Zai pit also collect water and concentrate water at the plant. This reduces the risk of water stress in a region of low and erratic rainfall (ADB, 2008). Another advantage of using pits is that they enhance the capture of water from onset of the rains and also enable precise application of organic and inorganic fertilizers. Although less weeds scored the least in the benefits of zai pits, it is usually an advantage as sub-soils excavated from the pits are put between the pits and vegetation growth is unlikely to grow on infertile soils. It is difficulty to use animal traction and hence this makes it a challenge for large scale farmers (Fatondji *et al*., 2009).

4.2.6 Predictors of zai system adoption by farmers in Tharaka Nithi County

A logistic regression analysis was conducted to predict adoption of zai system for 291 households using non formal trainings, household size, number of groups, land inclination, formal title deed, fertility status, wealth status, received relief, sell farm produce, improved planting material, total farm size as predictors (Table 4.6). A test of the full model against a constant model was statistically significant, indicating that the predictors, as a set, reliably distinguished between adopters and non-adopters of zai system (chi square 90.107, $p<0.001$, df=13). Prediction success overall was 75.3% (74.4% for non-adopters and 76.2% for adopters) (Table 4.6). The Wald criterion demonstrated that non formal trainings, number of groups, fertility status, wealth status, received relief and sold farm produce made a significant contribution to prediction (Table 4.6).

Table 4.6: Prediction factors of zai system adoption by farmers in Tharaka Nithi County

Variables	B	S.E.	Wald	Df	Sig.	Exp(β)
Non-Formal Trainings (continuous)	1.04	0.27	15.08	1	0.001	2.81
Household Size (continuous)	0.15	0.08	3.55	1	0.059	1.16
No Groups (continuous)	0.49	0.16	9.53	1	0.002	1.62
Land Sloppy (0=No, 1=Yes)	0.49	0.34	2.12	1	0.145	1.64
Formal Title Deed (0=No, 1=Yes)	-0.42	0.34	1.51	1	0.221	0.66
Fertility Status(1=high, 2=moderate, 3=Poor)	1.08	0.46	5.45	1	0.02	2.95
Wealth Status (1=Rich, 2=Average, 3=poor)	1.43	0.57	6.23	1	0.013	4.17
Received Relief (0=No, 1=Yes)	1.53	0.37	16.78	1	0.001	4.63
Sell Farm Produce (0=No, 1=Yes)	2.05	0.84	5.97	1	0.015	7.75
Improved Planting Material (0=No, 1=Yes)	0.64	0.36	3.07	1	0.08	1.89
Total Farm Size (continuous)	0.03	0.04	0.49	1	0.482	1.03
Constant	-12.4	2.35	27.76	1	0	0

Household Size, land inclination fertility status, improved planting material and total farm size had no significant influence on the adoption rate of zai system (Table 4.6). Non formal training was significant and positively influenced adoption of the zai system. The exp (β) value associated with non-formal trainings attended by the household head was 2.814 (Table 4.6). The number of farmer groups a household head belonged had a positive effect on adoption of zai system. The exp (β) shows that, for 1-unit increase in number of groups the probability of adoption would increase by a factor of 1.625 (Table 4.6). The results also indicated that there was a statistically significant relationship between fertility condition of the land and adoption of zai pits at p=0.05 (Table 4.6). Wealth status of the household head had a positive effect on adoption of zai system. Farmers who were ranked poor were more likely to adopt the zai system as compared to those who were rich. The exp (β) value associated with wealth status was 4.166 (Table 4.6). Hence, with one unit increase of wealth status the odds for adoption would increase by 4.166. Received relief significantly (1%) and positively influenced the adoption of zai system by farmers (Table 4.6). The exp(β) showed that the odds of a farmer receiving relief food was 4.627 times likely to adopted compared to those who were not (Table 4.6). Household heads who sell farm produce had a significant (5%) and positive impact on adoption of zai system (Table 4.6). The exp (β) value associated with sale of farm produce as factor that influence adoption of zai system was 7.754 at p=0.05 (Table 4.6).

The results suggest that the more non-formal trainings a farmer attends on farming techniques, the more likely they are to adopt zai system. These results are consistent with Rogers (2003) innovation diffusion theory which postulated that information access is central in the process of innovation adoption. In most adoptions, extension services provided through formal and informal institutions are a key factor in making farmers aware of and enabling them to promote new agricultural technologies (Thapa and Rattanasuteerakul, 2011; Paudel and Thapa, 2004). Farmers who were members of many groups were more inclined to adopt zai system than those who were not. Farmer groups predispose farmers to increased learning opportunities about improved water harvesting technologies and exchange of information among themselves on the advantages of zai ignites them to apply the technology on their farms. Studies have also shown a positive relationship between adoption of conservation practices and membership in farmer organisations (Sobel *et al.*, 2001; Nyanga, 2012). The increased likelihood to adopt zai pits when farmers belonged to a farming group, could suggest that the groups were sources of information about the technologies and thus the current extension system emphasizes on group extension approach (Kimaru-Muchai *et al.*, 2014).

Farmers who perceived their farms to be low in fertility were more likely to adopt the zai system than those who perceived their soil fertility to be high. This is consistent with research findings by Tadesse and Belay (2004) who reported that farmers who feel that their farmlands are prone to soil erosion are more likely to adopt physical soil conservation measures than those who do not perceive the problem of soil erosion. Another observation made in the study was that farmers who were poor were more likely to adopt zai pit as a water harvesting technology. It implies that “wealthier” farmers may not invest more in zai pits which require to be dug manully while they might be using tractors for land preparation. These findings disagree with Kessler (2006) who reported that resources endowment had significant correlation with farmers’ investments in land management.

Results showed that farmers receiving relief food was more likely to adopted zai pits compared to those who were not. As indicated earlier most of the farmers were motivated to dig zai pits because of “cash for asset” agenda, hence those who benefited from the food donated by the NGOs were likely to dig zai pits so that they would gain support of food and other basic needs like education for their children. According to Bekele and Drake (2003) assistance from any source encourages farmers to adopt physical conservation measures. Farmers who sell produce are more likely to adopt zai pit technology than those who do not sell. This could be attributed to the fact that extra income earned by sales of farm produce is a motivation to the farmer. Similar studies have also found that earnings from farm produce are a major determinant of adoption of water harvesting techniques (He *et al*., 2007). Farmers who have income accrued from selling cereals and vegetables from the farm imply tendencies towards increasing yields by adoption of improved soil conservation technology (Tiwari *et al*., 2008). Araya and Asafu-Adjaye (2001) reported that extension programs about soil conservation that are likely to increase the income of farmers would influence the adoption of soil protection measures.

Possession of formal title deed had an insignificant negative impact on adoption of zai system. However, it is usually expected that farmers who have title deeds are more likely to adopt zai pits as compared to those who do not. Zai pits are inherently a long-term investment requiring security of tenure over land for an extended period of time. Many smallholder farmers who apply these technologies on leased land lose the benefit of their investments because the owners withdraw the land for their own use soon. Tenure insecurity explains farmers’ unwillingness to invest effort in measures to improve soil conservation and enhance fertility (Mulugeta *et al*., 2001;

Abera, 2003).

According to the logistic model land size, family size, sloppiness of land and use of improved planting material were not significant variables in adoption of zai pits (Table 4.6). The findings differ with those of Huenchuleo *et al*. (2012) who reported that the size of the farm size was major a predictor in the adoption of soil water conservation measures in Chile. These results also contradict the findings of Enki *et al*. (2001), Tadesse and Belay (2004) and Amsalu and de Graaff (2007) who identified significant positive influence of land size on farmers' decision to adopt soil conservation measures. In the highlands of Eritrea, a study by Araya and Adjaye (2001) indicated that family size was a significant variable affecting soil conservation efforts. This is because larger households will be able to provide the required labour force for the implementation of soil-conserving structures as constructing soil-conserving structures is labour intensive. Farmers in Tharaka Nithi County are more likely to depend on hired labour hence family size was not a major dependent on adoption of zai pit system. Anley *et al*. (2007) indicates that farmers were inclined to invest in conservation practices where their farm plots are located on higher slopes. This is attributed to the fact that most conservation practices are mainly used to control soil erosion in hilly areas and the benefits are also expected to be higher in these areas.

4.3 Effects of zai pits and selected organics/inorganics on Soil chemical properties, aggregate stability and soil moisture

4.3.1 Soil chemical Properties

The soil pH increased significantly at $p < 0.05$ in conventional planting with manure (CCM), conventional planting with cattle manure plus half rate NPK (CC30) and zai pit with cattle manure plus half rate NPK (ZC30) treatments (Table 4.7). There was a significant difference between the initial pH and pH at the end of the experiment of conventional planting with manure (CCM) at (*p*= 0.005). Another signficant difference also existed between initial pH and pH at the end on zai pit plus cattle manure (ZC) was at *p*=0.014 (Table 4.7). A significant difference between the baseline pH and at the end of the experiment was also observed with the CC30 treatment at (P=0.053) while for zai pit with cattle manure plus half rate NPK (ZC30) was (P=0.011). However, pH decreased under zai pits with no amendment and conventional practice with no amendments (Table 4.7). Conventional planting with cattle manure treatment significantly increased (*p*= 0.05) the pH by 1.31 as it improved from slightly acidic to slight alkaline. There was no significant difference in pH between zai pit and conventional practice with the same soil fertility amendments at the end of the experiment. For instance the pH for conventional planting plus cattle manure (CCM) and zai pit plus cattle manure (ZC) was not significantly different neither for conventional planting with full rate NPK (CF60) and zai pit with full rate NPK (ZF60) (Table 4.7). The results indicate that soil water conservation technique had no effect on the pH but soil fertility amendment had positive effect.

Table 4.7: Soil chemical properties (0–15 cm) at the beginning of SR13 and end of SR14 season at Ciakariga, Tharaka Nithi County Kenya

Soil parameters	Soil pH(H_2O)			Total Nitrogen%			Total Organic Carbon%			Phosphorous ppm			Potassium me%		
Treatment	Begn	End	t	Begn	End	t	Begn	End	t	Begn	End	t	Begn	End	t
CCM	6.1	7.4	13.54**	0.16	0.21	2.79	1.5	2.1	2.92	23.3	42.3	1.26	0.7	1.94	6.66*
CC30	6.1	6.9	4.15*	0.16	0.19	1.44	1.5	1.87	1.58	23.3	52.7	1.43	0.7	1.69	7.96*
CF60	6.1	6.1	0.44	0.16	0.16	0	1.5	1.52	-0.1	23.3	60.0	3.95*	0.7	0.55	-1.13
CN0	6.1	6.0	-3.13	0.16	0.14	-0.92	1.5	1.41	-0.91	23.3	43.3	6.93*	0.7	0.57	-1.03
CT	6.1	6.5	2.31	0.16	0.19	1.12	1.5	1.92	1.15	23.3	71.7	4.14*	0.7	1.26	2.03
CT30	6.1	6.5	1.09	0.16	0.20	2.14	1.5	1.96	2.37	23.3	71.0	2.66	0.7	1.36	1.61
ZC	6.1	7.0	8.23*	0.16	0.18	4.00*	1.5	1.82	3.25	23.3	67.3	3.54	0.7	1.01	5.85*
ZC30	6.1	6.7	9.18*	0.16	0.15	-0.55	1.5	1.48	-0.82	23.3	61.7	11.50**	0.7	0.86	5.03*
ZF60	6.1	6.2	0.49	0.16	0.15	-0.48	1.5	1.46	-0.48	23.3	58.3	7.00*	0.7	0.38	-3.82
ZN0	6.1	6.0	-0.14	0.16	0.14	-0.8	1.5	1.42	-1.07	23.3	48.3	8.66*	0.7	0.45	-9.53*
ZT	6.1	6.2	1.4	0.16	0.16	0.19	1.5	1.56	0.09	23.3	48.3	15.21**	0.7	0.77	1.2
ZT30	6.1	6.4	0.99	0.16	0.15	-0.23	1.5	1.51	-0.27	23.3	50.0	16.00**	0.7	0.73	1.44

Begn –Beginning of experiment SR13, End-End of SR14 * significant at p=0.05, ** Significant at p=0.01

ZC=Zai pits +cattle manure, ZT =Zai pits +Tithonia, ZF60=Zai pits + 60 kg N ha^{-1} , ZC30= Zai pits +Cattle manure + 30 kg N ha^{-1} , ZT30= Zai pits + Tithonia + 30 kg N ha^{-1} , ZNO= Zai pits with no inputs, CCM= Conventional planting+cattle manure, CT=Conventional planting+Tithonia, CF60=Conventional planting + NPK 60 kg N ha^{-1}, CC30= Conventional planting + Cattle manure + 30 kg N ha^{-1}, CT30= Conventional planting + Tithonia + 30 kg N ha^{-1} ,CNO=Conventional planting with no inputs

Nitrogen content was significantly different ($p < 0.05$) in all the treatments at the end of the experiment. Nitrogen content increased statistically under zai pit soil water conservation techniques with cattle manure at ($p=0.05$). The nitrogen content for conventional planting with full rate NPK (CF60) did not change, however it decreased by 0.01 in conventional planting with full rate NPK (CF60) (Table 4.7). It was observed that conventional planting with tithonia plus half rate NPK (CT30) and conventional planting with cattle manure plus half rate NPK (CC30) resulted in increase in nitrogen content. Zai pit with tithonia plus half rate NPK (ZT30) and zai pit with cattle manure plus half rate NPK (ZC30) had a decrease in nitrogen content although the differences were not significant on the four treatments.

Carbon content followed the same sequence as nitrogen; conventional planting with manure (CCM) treatment had the highest carbon content followed by conventional planting with tithonia plus half rate NPK (CT30), conventional planting plus tithonia (CT) and conventional planting with cattle manure plus half rate NPK (CC30), respectively. Zai pit soil water conservation technique combined with full rate NPK (ZF60) had reduced more in carbon content as compared to conventional planting with full rate NPK (CF60) although the changes were not statistically different (Table 4.7). Cattle manure increased carbon content by 36% with conventional planting (CCM) while it increased the same nutrient by 17% with zai pit technique (ZC). Combined tithonia and half rate NPK with conventional planting (CT30) increased carbon by 27% while the same combination with zai pits (ZT30) had a decline of carbon by 2% (Table 4.7).

Potassium content was statistically higher ($p=0.05$) in conventional planting plus cattle manure (CCM) treatment as compared to zai pit plus cattle manure (ZC) treatment and it was also significantly higher (*p*=0.05)in conventional planting plus tithonia (CT) as compared to zai pit plus tithonia (ZT) (Table 4.7). Zai pit with cattle manure plus half rate NPK (ZC30) and zai pit with tithonia plus half rate NPK (ZT30) had significantly lower (*p*=0.05) potassium content compared to conventional planting with cattle manure plus half rate NPK (CC30) and conventional planting with tithonia plus half rate NPK (CT30), respectively (Table 4.7). Zai pit with full rate NPK (ZF60) had the lowest potassium content and it recorded the highest decline in potassium content while conventional planting plus cattle manure (CCM) recorded the highest increment. Cattle manure increased potassium content by 188% with conventional planting but it increased by 49% with zai pits (Table 4.7).

At the end of the experiment, soil pH under the conventional planting with no Manure (CNO) treatment was medium acid (pH =5.98) pH was slightly acidic for other treatments the except for conventional planting with manure (CCM) which was slightly alkaline (pH=7.38) at the end of the experiment. Increment of soil pH following application of manure was also observed by Wildemeersch *et al*. (2015) who reported that pH rose from 4.2 to 5.0 due to application of cattle manure. Other studies have also reported significant increase in pH with manure application (Mucheru-Muna *et al*., 2014; Mutegi *et al*., 2012; Mugwe *et al*., 2009; Mucheru-Muna *et al*., 2007). The pH range in these treatments is suitable for availability of beneficial nutrients such as phosphorus (P), magnesium (Mg) and calcium (Ca). This increase in measured pH values in conventional practice plus cattle manure (CCM) could be attributed to the increase in soil organic carbon content.

Soil organic was found to rise significantly for the conventional planting treatments provided with sole organics and combined organics and inorganics, with the range of +0.33 to 0.56 g kg^{-1} but decreased in conventional planting with full rate NPK (CF60), conventional planting without input (CNO), zai pit with cattle manure plus half rate NPK (ZC30), zai pit with full rate NPK (ZF60) ZN0 and zai pit with tithonia plus half rate NPK (ZT30) (Table 4.7). Other studies have also indicated that sole organics or in combination with inorganic fertilizer are more effective in increasing SOC and its fractions than inorganic fertilizer alone mainly due to the significant increase in C input with the organic application (Purakayastha *et al*., 2008; Gong *et al*., 2009). Results also indicate that the total N content remained low with levels ranging from 0.14 to 0.21 g kg^{-1}. This is in agreement with Bation *et al*. (2003) who reported that total nitrogen levels range from 0.03 to 2.26 g kg^{-1} in semiarid soils of West African countries. Higher nitrogen content realized in treatments of conventional planting combined with cattle manure compared to zai pit with cattle manure has also been supported by Fatondji *et al*. (2002).

Overall the results of this study indicate that zai pits have insignificant effects on soil chemical properties unlike other studies that have reported higher impacts of zai treatments on soil chemical properties in Burkina Faso (Sawadogo *et al*., 2008; Zougmoré *et al*., 2004). The high nutrient content of minerals found in conventional planting plus cattle manure (CCM) treatment could be attributed to the high nutrient content found in the cattle manure (Bayu *et al*., 2005) as well as the low leaching of nutrients in surface application as compared to zai pit technology (Fatondji *et al*., 2009). According to Fatondji *et al*. (2009) decomposition coefficient of cattle manure placed on the soil surface was 48% higher than in the zai ($p = 0.048$). Whereas there could be some losses of nutrients due to run off, water harvested in the pit may intensify the risk of nutrient leaching and hence this may have contributed to the low nutrient found in zai treatments. Fatondji *et al*. (2011) pointed out that zai pit improves soil water but at the same time it can lead to loss of nutrients, particularly nitrogen. It is important to mention that zai pit treatment had recorded stover and grain yields which may be an indicator of high mineral uptake by the plants and thus low nutrients available in the soil as it had been reported by Fatondji *et al*. (2002).

4.3.2 Effects of zai pits and selected organics/inorganics on aggregate stability

The mean weight diameter (MWD) of soil aggregates at the depth of 0-15cm are shown in Figure 4.2. The aggregate stability for the soils from zai pits and a combination of tithonia and half rate NPK treatment had the highest significant ($p<0.05$) MWD of 21.43 mm compared to other treatments (Figure 4.2). This was followed by conventional planting with no treatment and zai pit with tithonia with mean weight diameter (MWD) of 21.04 mm and 20.89 mm, respectively (Figure 4.2). There was a significant ($p<0.05$) MWD difference between zai treatment with tithonia and half rate NPK (ZT30) and conventional planting with tithonia and half rate NPK (CT30). The aggregate stability of zai and sole tithonia (ZT) was significantly higher ($p<0.05$) than conventional planting with sole tithonia (CT). Zai pit in combination with cattle manure (ZC) and half rate NPK (ZC30) and conventional planting in combination with cattle manure and half rate NPK (CC30) had the lowest MWD of aggregates (Figure 4.2).

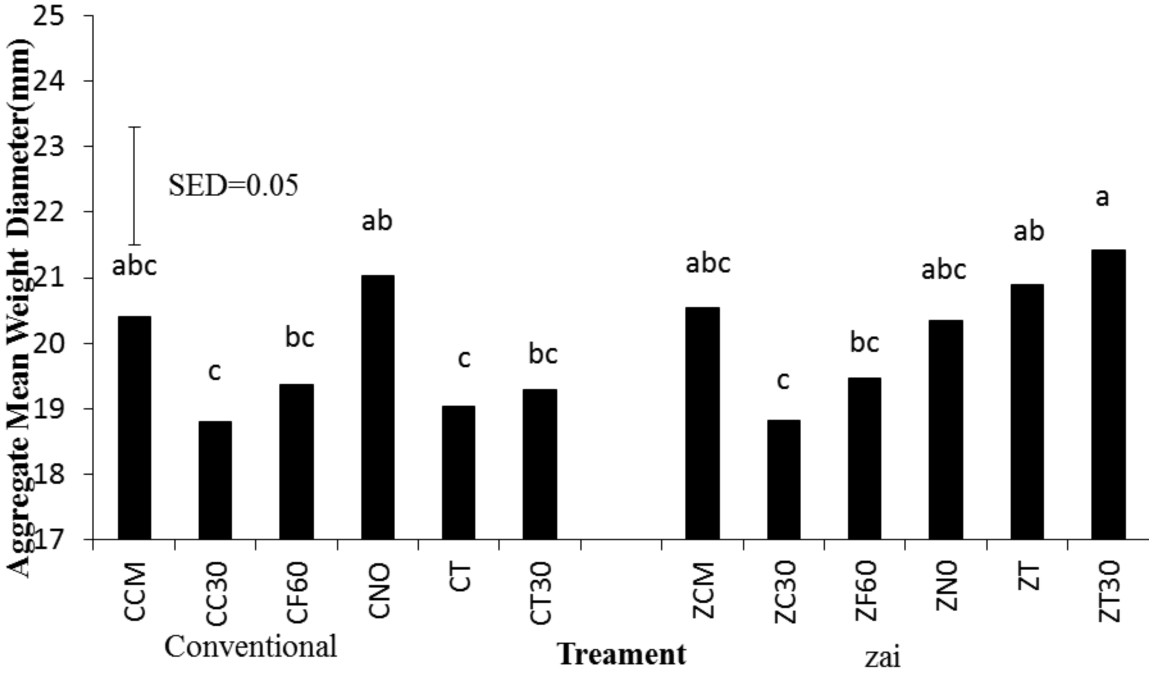

Figure 4.2: Soil aggregate stability (0–15 cm) under conventional and zai pit technique at the end of SR14 season at Ciakariga, Tharaka Nithi County Kenya

ZC=Zai pits +cattle manure, ZT =Zai pits +Tithonia, ZF60=Zai pits + 60 kg N ha^{-1} , ZC30= Zai pits +Cattle manure + 30 kg N ha^{-1} , ZT30= Zai pits + Tithonia + 30 kg N ha^{-1} , ZNO= Zai pits with no inputs, CCM= Conventional planting+cattle manure, CT=Conventional planting+Tithonia, CF60=Conventional planting + NPK 60 kg N ha^{-1}, CC30= Conventional planting + Cattle manure + 30 kg N ha^{-1}, CT30= Conventional planting + Tithonia + 30 kg N ha^{-1} ,CNO=Conventional planting with no inputs
Same superscript letters in same column denote no significant difference between treatments at p=0.05

Soil mean weight diameter was significantly affected by tillage system and amendments application at 0-15 cm suggesting that zai increased soil aggregation compared to the conventional planting system (Figure 4.2). Higher mean weight diameter of aggregates was recorded in zai tillage system with similar amendments as compared to conventional planting. However, mean weight diameter of aggregates for zai planting with no amendments was less than conventional planting with no amendments. Among the zai pit soil water conservation techniques, zai pits in combination with tithonia and half rate NPK (ZT30) had the highest MWD followed by zai pit with sole tithonia (ZT), zai pit with cattle manure (ZC), zai with no input (ZNO), zai with sole mineral fertilizer and the lowest was zai with cattle manure plus half rate NPK (ZC30) (Figure 4.2). In conventional practice, the MWD of aggregates was highest in conventional practice with no amendments (CNO), then conventional planting with cattle manure (CCM) followed by conventional planting with full rate mineral fertilizer (CF60) and conventional planting with tithonia in combination mineral fertilizer (CT30) (Figure 4.2). The lowest MWD of aggregates was recorded in conventional planting with cattle manure plus half rate NPK (CC30) (Figure 4.2).

Soil aggregate stability is one of the most important soil physical properties that affect the movement and retention of water, aeration, soil erosion and soil biological activity (Amezketa *et al.*, 2003). The results of this study shows better stability in the zai pit system compared with conventional planting (Figure 4.2). Previous studies indicate aggregate stability is highly influenced by the intensity of tillage (Al-Kaisi *et al.*, 2014). Better aggregate stability is reported in low-tillage systems compared with conventional tillage system (Gathala *et al.*, 2011; Wright *et al.*, 2010). The reason for this could be related to high levels of carbon in the no and low tillage systems (Al-Kaisi *et al.*, 2014). In this study zai pit system is considered as a low tillage system since there is less disturbance of soil (Twomlow *et al.*, 2008). Conventional tillage is known to affect soil aggregation directly by physical disruption of the macroaggregates and indirectly through alteration of biological and chemical factors (Barto *et al.*, 2010). Ghuman and Sur (2001) and Ngetich *et al.* (2008) observed a significantly greater MWD of soil aggregates in the minimally tilled treatments as compared to conventionally tilled treatments. Reduction in aggregates stability with cultivation has also been reported also by Lal (2008). Thus, there is reduced aggregation in conventional tillage in comparison with low tillage systems (Yalcin and Cakir, 2006).

The mean weight diameter of aggregates in conventional planting with no inputs (CNO) was also observed to be high as compared to soil aggregates in conventional practice with amendments. This is in contrast to the findings that addition of organic and inorganic amendments improves aggregate stability (Wang *et al.*, 2013). Lack of physical disruption of soil aggregates while applying the fertilizers may have contributed to the soil stability in conventional planting with no amendments. A field experiment conducted on the Loess Plateau of China showed that soils treated with organic fertilizer treatments improved soil aggregate while reduced aggregation was recorded in soils with no fertilizers (Wang *et al.*, 2013). In a study by Kushwaha *et al.* (2001) significant positive correlation between organic carbon and aggregate stability was reported. Du *et al.* (2007) observed that long-term application of fertilizers especially organic fertilizer played an important role in increasing aggregate stability on surface soil. The increase of aggregate stability among organic treated soils may be attributed to increased microbial biomass and consequently the formation of extra cellular polysaccharides which act as the good cementing agent of soil aggregates (Du *et al.*, 2007). However, according to Asgari *et al.* (2014) stability of soil aggregates is as a result of mixed effect of other factors not just the effect of soil organic carbon. The findings of this study demonstrate that tillage system and amendments applied on the soil have a significant effect on aggregate stability of the soils.

4.3.3 Effects of zai pits on soil moisture content

Moisture content was recorded fortnightly during the SR 14 and LR 14 seasons (Appendix 111). During the SR 14 season, ten days after sowing, with accumulative rainfall of 11.63 mm then a 5 day dry spell, conventional planting plus tithonia (CT) had the highest volumetric water content (VWC) at 5 cm depth followed by conventional planting plus cattle manure (CCM) (Figure 4.3Q). Among the zai treatments, zai pits plus tithonia (ZT) had the highest while zai pits with no inputs (ZNO) had the lowest VWC. The volumetric water content for conventional planting plus cattle manure (CCM) was 6.6 % higher than zai pits plus cattle manure (ZC) while conventional planting with no inputs (CNO) was 48% higher than zai pits with no inputs (ZNO) at 5 cm depth (Figure 4.3Q). At 35 cm depth, zai pits plus tithonia (ZT) had the highest VWC followed by zai pits plus cattle manure (ZC) and zai pit with cattle manure plus half rate NPK (ZC30), respectively. Among the conventional treatments, conventional planting without input (CNO) had the highest VWC while conventional planting plus tithonia (CT) had the lowest moisture content at 35 cm depth (Figure 4.3Q). The VWC for zai pit plus tithonia (ZT) was 110% significantly higher (p=0.05) than conventional planting plus tithonia (CT) at the depth of 35 cm, while VWC for zai pits plus cattle manure (ZC) was 54.4% higher than conventional planting plus cattle manure (CCM) (Figure 4.3Q).

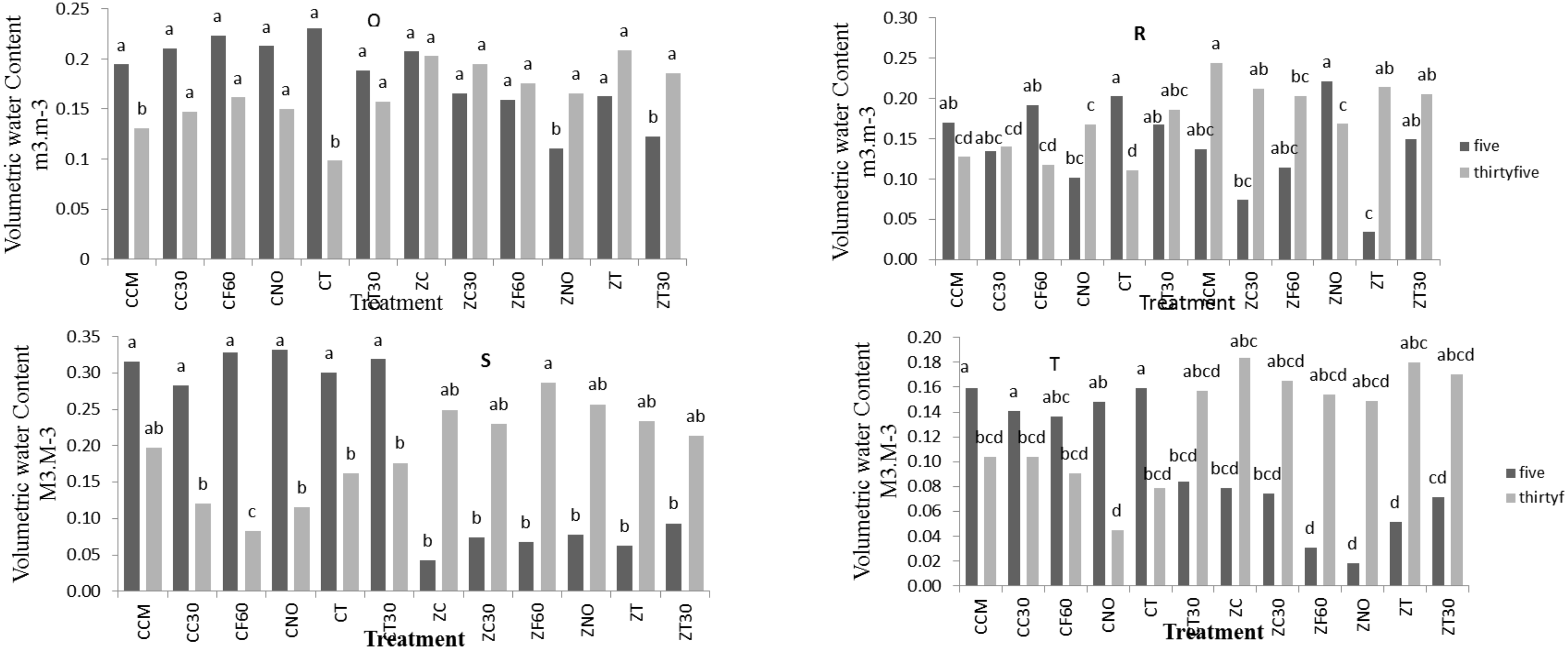

Figure 4.3: Moisture content in different days of the experiment under conventional and zai pit soil water conservation technique at 5 cm and 35 cm depth at Ciakariga, Tharaka Nithi County

Q=10 days after sowing SR14; R=52 days after sowing SR14; S=49 days after sowing LR2014; T=119days after sowing LR14

Fifty two days after sowing during the SR14, with accumulative rainfall of 249.7 mm and a dry period of 20 days, zai pits with no inputs (ZNO) had the highest moisture content followed by conventional planting plus tithonia (CT) at 5cm depth. At the same depth zai pit plus tithonia (ZT) had the lowest moisture of 0.034 $m^3.m^{-3}$ (Figure 4.3R). Among the conventional treatments, conventional planting without input (CNO) had the lowest VWC while conventional planting plus tithonia (CT) had the highest VWC at the depth of 5 cm (Figure 4.3R). Zai pits with no inputs (ZNO) had highest volumetric water content at the depth of 5cm while zai pit plus tithonia (ZT) had the lowest among the zai pit treatments. At 35 cm depth zai pits plus cattle manure (ZC) had the highest VWC followed by zai pit plus tithonia (ZT) while zai pits with no inputs (ZNO) had the lowest (Figure 4.3R). The lowest VWC at 35 cm depth was observed on conventional planting plus tithonia (CT) treatments and conventional planting without input (CNO) was the highest among the conventional practice (Figure 4.3R).

On the 49th day after sowing during the LR14, after 11 days of dry spell and then a rainfall of 14.9mm, conventional planting without input (CNO) had the highest VWC at 5 cm depth while zai pit plus cattle manure (ZC) had the lowest (Figure 4.3S). Among the conventional practices, conventional planting without input (CNO) was the highest followed by conventional planting with full rate NPK (CF60) then conventional planting plus tithonia (CT), respectively. Among the zai pit treatments, zai pit with tithonia plus half rate NPK (ZT30) had the highest VWC followed by zai pit without input (ZNO) while the least was zai pit plus cattle manure (ZC) at 5 cm depth (Figure 4.3S). Actually, VWC for zai pit without input (ZNO) was 118% higher than conventional planting without input (CNO) at 5 cm depth (Figure 4. 3S). At the depth of 35 cm, zai pit with full rate NPK (ZF60) was the highest followed by zai pit without input (ZNO) (Figure 4.3S). This implied that water infiltrated fast into the lower levels of the profile with little rainfall after a dry period in treatment with zai pits with no organics. However, at the same depth of 35 cm, conventional planting with full rate NPK (CF60) had the lowest followed by conventional planting without input (CNO) while conventional planting plus cattle manure (CCM) had the highest VWC (Figure 4.3S). This is possibly because the amount of rainfall that hit the soil on conventional planting without input (CNO) and conventional planting with full rate NPK (CF60) treatment may have evaporated before it reached the lower levels while the organics in conventional planting may have contributed to the easy percolation of water in treatments with organic amendments.

On the 119th day after sowing during the LR14, after 69 days of dry spell, zai pit without input (ZNO) had the lowest VWC followed by zai pit with full rate NPK (ZF60) at 5 cm depth. Among the zai treatments, zai pit plus cattle manure (ZC) had the highest VWC followed by zai pit with cattle manure plus half rate NPK (ZC30) at 5 cm depth (Figure 4.3T). At the same depth conventional planting plus cattle manure (CCM) had the highest followed by conventional planting plus tithonia (CT) among the conventional practice. At 35 cm depth, zai treatments had more VWC than conventional treatments (Figure 4.3T). Plate 4.2 indicates that 119 days after sowing, sorghum crop under zai pit with cattle manure was still appearing greener as compared to that one under conventional planting with cattle manure.

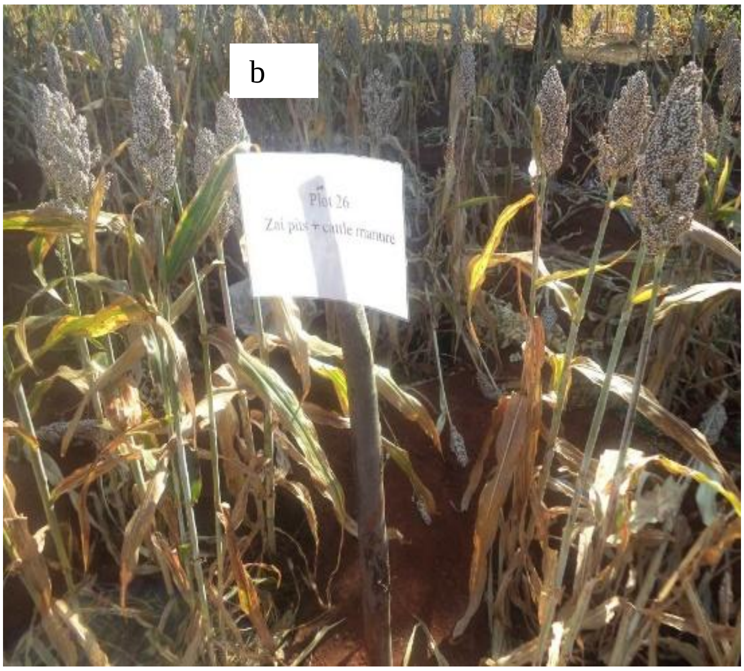

Plate 4.2: Sorghum crop as it appeared 119 days after sowing a=Conventional (Flat planting plus cattle manure); b=Zai pit plus cattle manure

Zai pit without input (ZNO) had the lowest VWC among the zai treatments while zai pit plus cattle manure (ZC) had the highest VWC (Figure 4.3T) Conventional planting plus cattle manure (CCM) had the highest among conventional practice while conventional planting without input (CNO) had the lowest VWC at the depth of 35 cm (Figure 4.3T). The VWC for zai pit with full rate NPK (ZF60) was significantly (P=0.05) higher than zai pit plus cattle manure (CF60) by 247% (Figure 4.3T).

Low VWC for zai treatments was observed at the 5 cm depth as compared to conventional treatments while high volumetric water content was observed at the depth of 35 cm for zai treatments as compared to conventional treatments (Figure 4.3). This implies that more water percolated into the lower levels of the profile in zai pits than in conventional planting. Conversely, the moisture found near the soil surface on conventional treatments is at risk of being lost through surface run off and through evaporation. After a dry spell of 20 days, it was observed that ZNO had more moisture at 5 cm depth as compared to conventional treatments and other zai treatments (Figure 4.3). This could have been attributed to more storage of moisture at the higher levels as a result of improved structure of soil hence more water being held by the soil molecules thus little water was lost through evaporation. The differences in volumetric soil water content between zai pit and conventional practice could be due to the water harvesting characteristic of the zai pit technique.

According to observations shown on Plate 4.2, sorghum crop under conventional planting was drier that the one under zai pit. This could be attributed to the fact that more moisture had been retained in zai pit unlike in conventional planting. Zai treatments with organic amendments had more VWC than treatments without organics at the 35 cm depth. This findings suggests that organic amendments enhanced water infiltration to the lower levels of the profile.

It was also observed that after a dry spell then rainfall, more VWC at the deeper layers is likely to be observed at the non- organic treatments. This is possibly because the organics absorb any water that get into the soil hence little or no water reaches the lower profiles. Increased VWC at the depth of 35 cm for CNO treatments compared to other conventional treatment observed in the experiment could also be associated with the high aggregate stability observed with CNO (Figure 4.2). In both conventional and zai treatments with no amendments less VWC was observed at 35 cm depth after a long duration of dry spell. This may be attributed to factors such as loss of water through evaporation which may not encourage retention and infiltration of water to the lower depths.

These findings are in line with observations that were made by Fatondji *et al*. (2006) that breaking surface crust and digging pits was highly favourable for infiltration of water compared to the conventional treatments. Zai pits were observed to improve soil water storage (Vohland and Barry, 2009). Fatondji *et al.* (2006) also reported that wetting front was shallower on non-zai-treated plots compared to zai treatments. Volumetric soil water content (VWC) was higher at deeper layers in the zai treatments than in conventional treatments even towards the end of the season. Observations made in the experiment also agree with the findings of other studies which report that increased organic matter content of the soil have a positive effect on the soil water holding capacity (Overstreet and DeJong-Huges, 2009). Shaheen *et al*. (2010), in a research work done to evaluate water use efficiency on sorghum production found that organic matter application had a significant beneficial impact on soil water conservation and nutrient supply for crop production. Blanco-Canqui *et al*. (2015) observed that manure application reduced compatibility and increased water retention in semiarid soils. Zai pits without amendments did not significantly increase soil moisture when compared to conventional planting without amendments (Kaluli *et al*., 2015). Observation in this study show that combination of organic amendments with zai pits helps to promote moisture retention as well as limit water loss through evaporation or by runoff.

4.4 Objective 3: Effects of zai pits in combination with selected organics / inorganics technologies on sorghum yields

4.4.1 Effects of zai pit on sorghum production during SR13, LR14 and SR14 seasons in Ciakariga, Tharaka Sub-County

The results indicated that zai pit as a water harvesting technique and fertility amendments had significant ($p \leq 0.001$) effect on sorghum grain yields (Table 4.8). The grain yields were mainly higher in those treatments with zai as a soil water conservation technique regardless of the amendments. However, LR14 season yields from conventional planting with tithonia (CT) were higher than zai pits with tithonia (ZT) although not statistically different at $p<0.05$ (Table 4.8). In SR13 season, zai pit with tithonia (ZT) treatment resulted in highest yields (4.3 Mg ha^{-1}) followed by zai pit with cattle manure (ZC) treatment (4.23 Mg ha^{-1}). During the LR14 season the treatment with zai pit with cattle manure (ZC) and zai pit with tithonia plus half rate NPK (ZT30) had the best grain yields of 0.34 Mg ha^{-1} and 0.25 Mg ha^{-1}, respectively (Table 4.8). Zai pits with cattle manure (ZC) and zai pits with full rate NPK (CF60) had the highest yields compared to other treatments in the SR14 season (Table 4.8). It is important to point out that grain yields and stover yields were lowest during the LR14 (Table 4.8). The highest grain and sorghum yields for LR14 were lower than the control for both SR13 and SR14 cropping season (Table 4.8)

Table 4.8 : Grain and stover yields for zai pits and conventional practices for SR13, LR14 and SR14 seasons in Ciakariga Tharaka Sub-county

	Grain yields Mg/ha			Stover yields Mg/ha		
Treatment	**SR13**	**LR14**	**SR14**	**SR13**	**LR14**	**SR14**
ZT	4.30^{a}	0.21^{bc}	3.78^{ab}	9.57^{b}	1.73^{ba}	11.30^{a}
ZC	4.23^{ab}	0.34^{a}	4.18^{a}	8.15^{b}	1.96^{a}	8.89^{b}
ZT30	3.96^{ab}	0.25^{b}	3.30^{bcd}	12.53^{a}	1.79^{ab}	12.53^{a}
ZC30	3.92^{ab}	0.19^{bc}	3.57^{abc}	8.02^{bc}	1.54^{abc}	9.26^{b}
ZF60	3.48^{ab}	0.18^{bc}	4.17^{ab}	9.01^{b}	1.30^{bc}	9.01^{b}
ZN0	1.96^{c}	0.03^{d}	1.00^{e}	4.75^{d}	0.21^{d}	4.75^{c}
CT	3.75^{ab}	0.24^{b}	3.75^{abc}	5.93^{cd}	1.65^{ab}	6.11^{c}
CCM	3.71^{ab}	0.18^{bc}	2.72^{d}	7.78^{bc}	1.67^{ab}	8.33^{b}
CT30	3.79^{b}	0.24^{b}	3.11^{cd}	8.70^{b}	1.63^{ab}	8.64^{b}
CC30	3.71^{ab}	0.18^{bc}	3.57^{abc}	7.84^{bc}	1.4^{bc}	8.46^{b}
CF60	3.32^{ab}	0.14^{c}	3.82^{ab}	8.09^{bc}	1.11^{c}	8.09^{b}
CN0	1.76^{c}	0.03^{d}	0.79^{e}	4.63^{d}	0.19^{d}	4.62^{c}
Fvalue	6.51	11.23	12.90	6.68	10.26	14.47
p	0.001	<0.001	<.001	<.001	<.001	<.001
LSD	0.8615	0.07	0.76	2.2	0.5057	1.6162
R-Square	0.791	0.87	0.88	0.795849	0.856865	0.894101

ZC=Zai pits +cattle manure, ZT =Zai pits +Tithonia, ZF60=Zai pits + 60 kg N ha^{-1}, ZC30= Zai pits +Cattle manure + 30 kg N ha^{-1}, ZT30= Zai pits + Tithonia + 30 kg N ha^{-1}, ZNO= Zai pits with no inputs, CCM= Conventional planting + cattle manure, CT=Conventional planting+Tithonia, CF60=Conventional planting + NPK 60 kg N ha^{-1}, CC30= Conventional planting + Cattle manure + 30 kg N ha^{-1}, CT30= Conventional planting + Tithonia + 30 kg N ha^{-1} ,CN0=Conventional planting with no inputs

Same superscript letters in same column denote no significant difference between treatments at p=0.05

During the SR13 season, zai pit with tithonia plus half rate NPK (ZT30) grain yields were higher than conventional planting with tithonia plus half rate NPK (CT30) grain yields by 6% (Table 4.8). Zai pit with tithonia (ZT) grain yields were higher than for conventional planting with tithonia (CT) by 14%. Zai pit with tithonia (ZT) treatment had 14% grain yield increment compared to conventional planting with tithonia (CT) (Table 4.8). The grain yields for zai pit without amendments (ZNO) was 11% higher than conventional planting without amendment (CNO). During the LR14, zai pit with cattle manure (ZC) was 85% significantly higher (*p*=0.001) than conventional planting with cattle manure (CCM) (Table 4.8). In the same season zai pit with full rate NPK (ZF60) was higher than conventional planting with full rate NPK (CF60) by 27.9% while zai pit with tithonia (ZT) was 14% lower than conventional planting with tithonia (CT) (Table 4.8). The least grain yield difference experienced during the LR14 season was between zai without amendments (ZNO) and conventional planting without amendments (CNO) (Table.4.8). During the SR14, grain yields of zai pit with cattle manure (ZC) were higher significantly (p=0.001) by 53.7% than conventional planting with cattle manure (CCM) (Table 4.8). There was no grain yield difference between zai pit with cattle manure plus half rate NPK (ZC30) and conventional planting with cattle manure plus half rate NPK (CC30). In addition, conventional planting without amendments (CNO) was 26.1% lower than zai pit without amendments (ZNO) although not significantly different. There was minimal difference between grain yield of zai pit with tithonia (ZT) and conventional planting with tithonia (CT) in the SR14 season (Table 4.8).

Zai pit with tithonia plus half rate NPK (ZT30) treatment had the highest stover yields of 12.53 Mg ha^{-1} followed by zai pit plus tithonia (ZT) with 9.57 Mg ha^{-1} during the SR13. In LR14, all stover yields for zai pit and conventional practices with amendments were significantly higher than the control at p=0.05. A combination of zai pit with cattle manure treatment had the highest stover yields followed by zai pit with tithonia plus half rate NPK (ZT30) and zai pit plus tithonia (ZT) with stover yields of 1.96 Mg ha^{-1}, 1.79 Mg ha^{-1} and 1.72 Mg ha^{-1}, respectively (Table 4.8) but there was no significant difference at $p<0.05$ during LR14 (Table 4.8). In SR14, stover yields for zai pit with tithonia plus half rate NPK (ZT30) and zai pit plus tithonia (ZT) treatments were significantly higher with 12.53 Mg ha^{-1} and 11.29 Mg ha^{-1}, respectively (Table 4.8), than all other treatments. According to the results, there was no significant difference in grain yields of conventional planting plus tithonia (CT), conventional planting with tithonia plus half rate NPK (CT30), conventional planting plus cattle manure (CCM) conventional planting with cattle manure plus half rate NPK (CC30) and conventional planting with full rate NPK (CF60) during the SR13 season (Table 4.8). In all the three seasons the stover yields and grain yields for both zai and conventional practices without amendments were not statistically different ($p<0.05$) (Table 4.8).

Grain yields and stover yields for zai pits with organic amendments were consistently higher for the three consecutive cropping seasons in comparison to zai pit combined with sole inorganic or combination of organic and inorganic fertilizer. The increased grain and stover yields from zai pits with amendments {zai pit plus cattle manure (ZC), zai pit plus tithonia (ZT), zai pit with tithonia plus half rate NPK (ZT30), and conventional planting with full rate NPK (CF60)} could be as a result of the applied amendments as well as from improved soil water status following high water infiltration. Zai pits tend to increase water availability in the root zone (Fatondji *et al.*, 2006) while amendments impact on soil fertility (Zanen *et al.*, 2008). Ncube *et al.* (2008) observed that zai pits increased grain yield of cowpeas by 8 fold while in South Africa, the planting basins improved the yields more than four fold. According to a study by Magombeyi and Taigbenu (2008), chololo pits (a variation of zai pits) resulted in highest yield in comparison to conventional treatments. In Masinga, Machakos county in Kenya, zai pit without fertilizer application significantly ($p < 0.05$) increased sorghum grain yields by 10 times over the plot without zai and with no ammendments in 1995 (Kathuli and Itabali, 2015).

Low grain and stover yields during the LR14 season indicated that the low rainfalls affected crop growth and consequently the yields. Ibrahim *et al*. (2011) reported that meteorological related parameters such as rainfall are the most critical factors affecting the yield of sorghum with increased rainfall resulting in increased yields. Kurukulasuriya and Mendelsohn (2006) demonstrated that climate variability directly affects crop yields with declining rainfall resulting in reduced crop yields. This is also in agreement with Ibrahim *et al*. (2011) who reported a positive correlation between total seasonal rainfall and yield, though the effect was not significant. Long term simulation using the Agricultural Production Simulator (APSIM) model indicated that crop failures can be experienced in both conventional and basin systems largely due to uneven distribution of rain events during the growing season (Ncube, 2008). In southern Zimbabwe significant yield gains were obtained from basin tillage compared to conventional farmer practice in both below average and above average rainfall seasons (Twomlow *et al*., 2008).

In all the three seasons, grain yields of conventional planting with amendments were higher than zai pit with no amendments. This implies that the benefits of zai pits are increased when combined with soil fertility amendments. The results agree with Fatondji *et al*. (2009) findings who reported that zai and conventional with amendments performed better than without amendments. This also concurs with several studies (Fosu *et al*., 2008; Kihara *et al*., 2009) that the yield or rain water productivity responses to fertility amendments are much higher than the response to the rainwater harvesting technologies alone. Combination of improved soil fertility and water management as in the case of the use of micro dosing of N fertilizer with tied ridges in Mozambique (Wall and Thierfelder, 2009) and zai pits with organic manures in Niger (Fatondji *et al*., 2009) has resulted to significant yields.

4.4.2 Effect of amendments on grain and stover yields

There was a significant difference of grain yields between zai with tithonia and zai without tithonia (ZT and ZNO) at (*P*=0.001) during the SR13 season (Table 4.9). Tithonia increased grain yields by 119.6% with zai while it increased grain yields by 113% with conventional planting (Table 4.9). In the SR13 season, cattle manure with zai (ZC) increased grain yields by 115.9% while conventional planting with cattle manure (CCM) technique increased by 110.6%. There was a significant difference between zai pit with cattle manure (ZC) and zai pit without amendments (ZNO) at (*P*=0.005) while a significant difference existed between conventional planting with cattle manure (CCM) and conventional planting without amendments (CNO) at (*P*=0.02) (Table 4.9). Full rate NPK increased grain yields by 77.5% with zai while it increased with 88.5% with conventional planting technique.

There was a significant difference between zai pit with full rate NPK (ZF60) and zai pit without amendment (ZNO) at (*P*=0.004) but there was no significant difference between conventional planting with full rate NPK (CF60) and conventional planting without amendments (CNO) during SR13 (Table 4.9). During the LR14 season, zai pits treated with cattle manure resulted in an increment of grain yields by 885% compared to zai pits with no amendments. In the same season conventional planting with cattle manure had 451% increment compared to plots treated with conventional planting with no amendments (Table 4.9). There was a significant increment (*p*<0.001) on grain yields in mineral fertilizer treated plots of zai pits (ZF60) by

407% but an insignificant increment of conventional plant planting technique with mineral fertilizers (CF60) compared to plots with no amendments (Table 4.9).

Table 4.9: Comparison of yields between conventional and zai pit planting technique with amendments and control in Tharaka Nithi County

		Short Rain 2013		Long Rain 2014		Short Rain 2014	
Yield	Treatment	Yield Mg/ha	t	Yield Mg/ha	t	Yield Mg/ha	t
Grain	ZC30	3.92	4.86*	0.19	12.06*	3.57	6.92*
	ZNO	1.96		0.03		1.00	
Stover	ZC30	8.02	2.76	1.54	7.25*	9.26	9.85**
	ZNO	4.75		0.21		4.75	
Grain	ZC	4.23	7.94*	0.34	10.38*	4.18	5.67*
	ZNO	1.96		0.03		1.00	
Stover	ZC	8.15	5.14*	1.96	8.99**	8.89	10.23**
	ZNO	4.75		0.21		4.75	
Grain	ZF60	3.48	6.16*	0.18	4.06	4.17	9.39**
	ZNO	1.96		0.03		1.00	
Stover	ZF60	9.01	6.04*	1.30	7.88**	9.01	6.04*
	ZNO	4.75		0.21		4.75	
Grain	ZT30	3.96	12.41**	0.25	8.82*	3.30	13.69**
	ZNO	1.96		0.03		1.00	
Stover	ZT30	12.53	17.86**	1.79	6.63*	12.53	17.86**
	ZNO	4.75		0.21		4.75	
Grain	ZT	4.30	9.89**	0.21	5.57*	3.78	16.25**
	ZNO	1.96		0.03		1.00	
Stover	ZT	9.57	3.23	1.73	3.35	11.30	10.59*
	ZNO	4.75		0.21		4.75	
Grain	CT30	3.79	7.21**	0.24	8.60*	3.11	7.16*
	CNO	1.76		0.03		0.79	
Stover	CT30	8.70	8.10*	1.63	11.86**	8.64	8.29*
	CNO	4.63		0.19		4.62	
Grain	CF60	3.32	4.30	0.14	3.58	3.82	6.84*
	CNO	1.76		0.03		0.79	
Stover	CF60	8.09	2.20	1.11	2.79	8.09	2.20
	CNO	4.63		0.19		4.62	
Grain	CC30	3.71	5.14*	0.18	4.27*	3.57	6.31*
	CNO	1.76		0.03		0.79	
Stover	CC30	7.84	6.20*	1.41	10.26**	8.46	4.18*
	CNO	4.63		0.19		4.62	
Grain	CCM	3.71	4.64*	0.18	8.34*	2.72	8.86**
	CNO	1.76		0.03		0.79	
Stover	CCM	7.78	2.66	1.67	10.42**	8.33	4.90*
	CNO	4.63		0.19		4.62	

Grain	CT	3.75	5.93*	0.24	19.62**	3.76	9.59**
	CNO	1.76		0.03		0.79	
Stover	CT	5.93	2.53	1.66	3.92*	6.11	3.09
	CNO	4.63		0.19		4.62	

ZC=Zai pits +cattle manure, ZT =Zai pits +Tithonia, ZF60=Zai pits + 60 kg N ha^{-1}, ZC30= Zai pits +Cattle manure + 30 kg N ha^{-1}, ZT30= Zai pits + Tithonia + 30 kg N ha^{-1}, ZNO= Zai pits with no inputs, CCM= Conventional planting + cattle manure, CT=Conventional planting+Tithonia, CF60=Conventional planting + NPK 60 kg N ha^{-1}, CC30= Conventional planting + Cattle manure + 30 kg N ha^{-1}, CT30= Conventional planting + Tithonia + 30 kg N ha^{-1} ,CN0=Conventional planting with no inputs
Same superscript letters in same column denote no significant difference between treatments at p=0.05 p<0.05 **P<0.001*

During the SR14 season, the difference between grain yields of zai with tithonia and zai without tithonia was significant at (*p*=0.03) at an increment of 279.3% while the difference between conventional planting technique with tithonia (CT) and without amendment was (*p*=0.002) at an increment of 375% (Table 4.9). Cattle manure increased grain yields by 320% with zai pits but it increased by 244.4% with conventional planting technique (Table 4.9). Full rate NPK fertilizer increased grain yields by 318% with zai pits while it increased by 383% with conventional planting technique (Table 4.9). A combination of half recommended rate of NPK and tithonia increased grain yields by 231% under zai pit (ZT30) while it gave an increment of 293% under conventional planting. In addition half recommended rate of fertilizer plus cattle manure increased grain yields by 257% under zai pit but increased grain yields by 352% under conventional planting (Table 4.9).During the SR13 season, zai pits plus half recommended rate of NPK fertilizer and tithonia increased stover yields significantly (*p*=0.001) by 164 % compared to control while it increased significantly (*p*=0.01) by 88% with conventional planting (Table 4.9). Sole tithonia increased stover yields significantly (*p*=<0.08) when applied in the pit by 101% but increased the stover yields significantly (*p*=0.09) by 88% when it was applied on the surface (Table 4.9). During the LR14 season, there was a significant difference between zai pits with cattle manure (ZC) and those without amendments (ZNO) (Table 4.9). Sole cattle manure increased stover yields significantly (p=0.01) by 835% under zai pits but increased significantly (p=0.08) by 800% with conventional planting (Table 4.9). In the same season half recommended rate of fertilizer with cattle manure increased stover yields significantly (p=0.03) under zai pits by 635% than when it was applied on the surface, it increased stover yields by 660% compared to control (Table 4.9). During the SR14 season half recommended fertilizer and tithonia increased stover yield significantly (p=0.05) by 164 % compared to control while it increased by 87% with conventional planting (Table 4.9). Tithonia increased stover yields significantly (p=0.03) when applied in the pit by138% compared to zai without amendment (Table 4.9). However, it increased the stover yields by 32% when it was applied on the surface compared to control (FN0) (Table 4.9).

During the SR13, zai pit with tithonia (ZT) had the highest grain yields followed by zai pit with cattle manure (ZC) (Table 4.9) while zai pit without amendments had the lowest stover and grain yields during the SR13 season (Table 4.9). In LR14 and SR14 seasons, zai plus cattle manure treatment had the highest grain yields among the zai treated plots (Table 4.9). Among the conventional planting techniques treatment, conventional planting with tithonia plus half rate NPK (CT30) had the highest stover yields followed by conventional planting with cattle manure plus half rate NPK (CC30) with stover yields of 8.64 Mg ha^{-1} and 8.45 Mg ha^{-1}, respectively in SR14 season (Table 4.9).

Higher grain and stover yields observed in treatments with tithonia over the control could have resulted from increased nitrogen availability and beneficial effects of applied organic matter leading to a more favorable soil condition. The results are in agreement with those obtained by Olabode *et al*. (2007) and Ademiluyi and Omotosho (2007) who reported better crop yields for tithonia. The results concur with the findings of Mugwe *et al.* (2009) who reported significant maize yield increase following application of tithonia. Another observation made was that the interactive effect of tithonia with zai pits yielded more than with conventional planting with tithonia. This could be explained by the fact that under zai conditions, the crop could have made better use of nutrient in tithonia than when tithonia was applied on the surface. Moreover, better moisture retention by zai pits as observed in the study may have attributed to favourable conditions for plant growth hence higher yields.

Higher yields obtained on plots under zai pits with cattle manure in comparison to conventional planting with cattle manure imply that there is better interaction between zai pit and cattle manure than conventional planting with cattle manure and hence more increment in grain yields. The increase in yields was possibly because cattle manure improves soil moisture content as well as the high levels of N realized from cattle manure (Lekasi *et al*., 2003; Onduru *et al*., 2008). This is in agreement with Graham (2010) who reported that application of cattle manure provided a significant yield increase of grain amaranth of 58.6% with the addition of cattle manure in comparison to control plots. According to Muhereza *et al*. (2014) majority of the farmers in Kampala attribute the use of cattle manure to increased yields.

The results demonstrate that mineral fertilizers also contributed to increase of yields on both planting techniques. A study on basin tillage system (a variation zai pits), showed that basins had higher chances of giving higher yields than the conventional system with application of nitrogen fertilizer (Ncube, 2008). Shrotriya (1998) reported that balanced application of NPK caused up to 122% increase in sorghum yield in India. The use of inorganic fertilizers and other soil amendments is essential to increase crop production and productivity (Panda, 2008; Rufino *et al.*, 2006). Apart from improving crop yields, fertilizer also increases the quantity of available crop residues used for livestock feed or as soil organic inputs (Bationo *et al.*, 2006). According to Okalebo *et al.* (2005), use of inorganic fertilizers containing major nutrients, even without micronutrients or organic inputs, can dramatically increase food production under many intensified systems (Okalebo *et al.*, 2005). Guo *et al.* (2007) noted that inorganic fertilizers released their nutrient rather fast for the plants to utilize. Simulation results using the Agricultural Production Systems Simulator (APSIM) model (Keating *et al.*, 2003) for a 1951–1999 rainfall period in southern Zimbabwe, suggested that farmers could increase their average yields by 50–100% by applying as little as 9 kg N ha^{-1}.

The results imply that combined organic and inorganic have a positive effect on the yields. A research study by Chivenge *et al.* (2009) indicated that combinations of organic and mineral fertilizers result in greater crop yields compared with sole organic or sole mineral fertilizers. This is also in agreement with Kimetu *et al.* (2004) who observed a general yield increase in crop yields following the combined application of tithonia with nitrogen fertilizers compared with sole tithonia. Other studies have shown that combinations of organic resources and mineral fertilizers result in greater crop yields compared with sole organic resources or sole mineral fertilizers (Mutegi *et al.*, 2012; Mtambanengwe *et al.*, 2006; Nyamangara *et al.*, 2003). This is as a result of positive interactions and complementarities between the organics and inorganic (Jeannin, 2012). Integration of organic and inorganic nutrient sources has been known to increase nutrient release and enhance uptake by plants leading to increased yields (Sanchez and Jama, 2002). Combined of organic and inorganic sources of nutrients addresses both the problem of inadequate mineral fertilizer as well as the large amounts of organic material required to meet crop nutrient demands (Mutegi *et al.*, 2012).

Lack of significant differences between zai pit without amendments and conventional planting without amendment is an indication that application of nutrients made insignficant differences in yields between the soil tillage techniques. Addition of amendments restores soil quality for plant growth by balancing pH, increasing water holding capacity, adding organic matter, restoring soil microbial activity, and reducing compaction (Allen *et al.*, 2007). The observations made in this objective indicate that zai pits in combination with organics/ inorganics yield better than conventional planting with similar amendments. Nonetheless, uses of conventional planting in combination with soil fertility amendments also have a positive effect on crop yields. Therefore, in addition to utilization of zai pits as a water harvesting strategy, application of soil fertility inputs play a major role in improvement of yields.

4.5 Objective 4: Economic potential of zai pits utilization in combination with selected ISFM on sorghum production

Zai pit with tithonia (ZT) treatments recorded the highest labour costs significantly at (p<0.001) followed by conventional planting with tithonia with labour cost of US$2874.5 ha^{-1} and US$2304.06 ha^{-1}, respectively (Table 4.10). The total labour cost for zai pit with cattle manure (ZC) was 139% significantly higher than conventional planting with cattle manure (CCM) while zai pit without input (ZNO) labour cost was 167% higher than conventional planting without input (CNO) (Table 4.10). There was a significant difference (p<0.001) of 40.1% labor cost between zai pit with tithonia plus half rate NPK (ZT30) and conventional planting with tithonia plus half rate NPK (CT30) (Table 4.10). The labour cost for conventional planting with tithonia (CT), conventional planting with cattle manure plus half rate NPK (CC30), conventional planting with cattle manure (CCM) and conventional planting with full rate NPK (CF60) was 503%, 54.4%, 29.9 % and 27.7%, respectively, higher than conventional planting without input (CNO) (Table 4.10). The labour cost for zai pit with tithonia (ZT) and zai pit with tithonia plus half rate NPK (ZT30) was 181.1% and 95.9% respectively, higher than zai pit without input (ZNO) (Table 4.10). The labour cost for conventional planting with tithonia plus half rate NPK (CT30) was 273.3% higher than conventional planting without input (CNO) (Table 4.10). Conventional planting without inputs (CNO) had the lowest labour cost of $382.07 ha^{-1}.

Table 4.10: Economic analysis on labour cost, total cost, total benefit, net benefit and BCR for three seasons SR13, LR14, SR14 in Tharaka Nithi County

Treatment	Labour Cost (US$)	Total Cost (US$)	Total Benefit (US$)	Net Benefit (US$)	BCR
CCM	496.48^{j}	763.15^{k}	2383.1^{c}	1620^{ab}	3.12^{b}
CC30	589.99^{i}	841.32^{j}	2654.5^{abc}	1813.2^{a}	3.15^{b}
CF60	487.97^{j}	723.97^{l}	2600.3^{bc}	1876.3^{a}	3.58^{a}
CNO	382.07^{k}	482.07^{m}	942.1^{d}	460.1^{ef}	1.95^{cd}
CT	2304.06^{b}	2404.06^{b}	2652.5^{abc}	248.4^{fg}	1.10^{f}
CT30	1426.33^{e}	1594.33^{e}	2576.5^{bc}	982.1^{cd}	1.62^{de}
ZC	1188.15^{f}	1454.82^{f}	3078.8^{a}	1623.9^{ab}	2.11^{c}
ZC30	1155.25^{f}	1406.58^{g}	2742.9^{abc}	1336.3^{bc}	1.95^{cd}
ZCT	2107.11^{c}	2290.45^{c}	2605.1^{bc}	314.7^{efg}	1.14f
ZF60	1076.09^{g}	1312.09^{h}	2818.2^{abc}	1506.1^{ab}	2.15^{c}
ZNO	1020.41^{h}	1120.41^{i}	1104.2^{d}	-16.2^{g}	0.94^{f}
ZT	2874.49^{a}	2974.49^{a}	3008.1^{ab}	33.6^{fg}	1.01^{f}
ZT30	1998.93^{d}	2166.93^{d}	2870.7^{ab}	703.8^{de}	1.32^{ef}
LSD	37.098	37.098	468.62	450	0.4096
P	<.0001	<.0001	<.0001	<.0001	<.0001

ZC=Zai pits +cattle manure, ZT =Zai pits +Tithonia, ZF60=Zai pits + 60 kg N ha^{-1} *, ZC30= Zai pits +Cattle manure + 30 kg N ha*$^{-1}$ *, ZT30= Zai pits + Tithonia + 30 kg N ha*$^{-1}$ *, ZNO= Zai pits with no inputs, CCM= Conventional planting + cattle manure, CT=Conventional planting+Tithonia, CF60=Conventional planting + NPK 60 kg N ha*$^{-1}$*, CC30= Conventional planting + Cattle manure + 30 kg N ha*$^{-1}$*, CT30= Conventional planting + Tithonia + 30 kg N ha*$^{-1}$ *,CNO=Conventional planting with no inputs*
Same superscript letters in same column denote no significant difference between treatments at p=0.05

In all the three seasons total costs were recorded highest on the zai planting with tithonia (ZT) treatments followed by conventional planting with tithonia (CT). Zai pit with tithonia treatment (ZT) was significantly higher ($p<0.001$) by 23.7% than conventional planting with tithonia treatment (CT) (Table 4.10). The total cost for zai pit with cattle manure (ZC) was 90.6% significantly higher (*p*<0.001) than zai pit with cattle manure (ZC) while zai pit without inputs (ZNO) total cost was significantly higher (*p*<0.001) than conventional planting without inputs (CNO) by 132.4% (Table 4.10). The total cost for zai pit in combination with cattle manure plus half rate NPK (ZC30) was 67.2% higher than conventional planting with cattle manure plus half rate NPK (CC30) while zai pit plus full rate NPK (CF60) total cost was 81.2% higher than conventional planting with full rate NPK (CF60) (Table 4.10). There was a significant difference (*p*<0.001) of 165% total cost between zai pit with tithonia (ZT) and zai pit without inputs (ZNO) during the three seasons (Table 4.10). There was significant difference (*p*<0.001) of 517% total cost between zai pit with tithonia (ZT) and Conventional planting without inputs (CNO) (Table 4.10) but a significant difference of 398.7% between conventional planting with tithonia (CT) and conventional planting without inputs (CNO).

The total cost for conventional planting with cattle manure plus half rate NPK (CC30), conventional planting with cattle manure (CCM) and conventional planting with full rate NPK (CF60) was 74.5%, 58% and 50%, respectively, higher than conventional planting without inputs (CNO) (Table 4.10). The total cost for zai pit with tithonia plus half rate NPK (ZT30), zai pit with cattle manure (ZC), zai pit with cattle manure plus half rate NPK (ZC30) and zai pit plus full rate NPK (CF60) was 93.4%, 29.8%, 25.5% and 17.1%, respectively, higher than zai pit without inputs (ZNO) (Table 4.10).

The zai pit with tithonia (ZT) and that with cattle manure (ZC) treatments' recorded significantly (*p*< 0.001) higher total benefits than all the other treatments in the three seasons (Table 4.10). The total benefits for zai pit with cattle manure (ZC) was

29.2% significantly higher ($p < 0.001$). A significant difference ($p < 0.001$) of 178.8% was recorded between the total benefits for zai pit with cattle manure (ZC) and that without inputs (ZNO) while zai pit with tithonia (ZT) recorded a difference of 172.4% with zai pit without inputs (ZNO) (Table 4.10). The total benefits for conventional planting combined with tithonia (CT) and conventional planting combined with cattle manure (CCM) were significantly ($p < 0.001$) higher than conventional planting without inputs (CNO) by 181.6% and 153%, respectively (Table 4.10). The total benefits for zai pits combined with tithonia and half rate NPK (ZT30) were 204% higher than conventional planting without inputs (CNO) while conventional planting combined with tithonia and half rate NPK (CT30) was 173% higher than conventional planting without input (CNO) (Table 4.10). Conventional planting without inputs (CNO) total benefits were significantly ($p < 0.001$) the lowest followed by zai pit without inputs (ZNO) although they were not significantly different at ($p < 0.001$). There was non- significant difference of 8.4% between the total benefits for zai pit with full rate NPK (CF60) and conventional planting with full rate NPK (CF60). The observed trend was that during the three consecutive experimental seasons, total benefits were high under the zai treated plots with amendments but low in both the planting techniques without amendments.

During the three seasons, the highest significant ($p<0.001$) net benefit was recorded by the conventional planting with full rate NPK (CF60) followed by the conventional planting with cattle manure plus half rate NPK (CC30) with net benefits of US$1876.3 ha^{-1} and US$ 1813.2 ha^{-1}, respectively (Table 4.10). The net benefits for zai pit with cattle manure plus half rate NPK (ZC30) were significantly lower than conventional planting with cattle manure plus half rate NPK (CC30) by

26.3% (p<0.001) (Table 4.10). Among the zai treatment technique, zai pit with full rate NPK (CF60) had the highest significant net benefit of US\$1506.1 ha^{-1} followed by zai pit with cattle manure plus half rate NPK (ZC30) with net benefit of US\$1336.3 ha^{-1} and the lowest was zai pits without inputs (ZNO) with negative net benefit of US\$-16.2 ha^{-1} (Table 4.10). This implied that the total cost for the treatment of zai without inputs was higher than the benefits.

Conventional planting with mineral fertilizer (CF60) had the highest significant (p<0.001) BCR of 3.58 followed by conventional planting with cattle manure plus half rate NPK (CC30) with a BCR of 3.15 (Table 4.10) The BCR for conventional planting with full rate NPK (CF60) was 66% lesser than for conventional planting plus cattle manure (CCM) (Table 4.10). Zai pit without input (ZNO) recorded BCR of 0.94 which was 98.2% lower than conventional planting without input (CNO) (Table 4.10). Conventional planting with cattle manure was significantly higher (p<0.001) than zai pit with cattle manure by 47.9% while conventional planting with tithonia was insignificantly higher than zai pit plus tithonia (ZT) by 9.1%. Benefit cost ration was increased by cattle manure, cattle manure plus half rate NPK and tithonia plus half rate NPK in zai pit treated plots by 117.6%, 114.2%, 97.8% and 34.3%, respectively, compared with zai pit without input (ZNO). The Benefit cost ratio (BCR) for conventional planting with full rate NPK (CF60), conventional planting with cattle manure plus half rate NPK (CC30) and conventional planting plus cattle manure (CCM) was higher by 83%, 61.1% and 59.8%, respectively, compared to conventional planting without input (CNO). The BCR for conventional planting plus tithonia (CT) and conventional planting with tithonia plus half rate NPK (CT30) was lower that 43.5% and 17.3% lower compared to conventional planting without input (CNO) (Table 4.10).

Labour was highest in zai pits combined with tithonia treatment but lowest in convention planting with no input. (CNO) (Figure 4.4). Total benefits were highest in zai pits combined with cattle manure treatment but lowest in convention planting with no input. (CNO) (Figure 4.4) Among the zai treatment technique, zai pit with full rate NPK (CF60) had the highest significant net benefit of US$1506.1 ha^{-1} followed by zai pit with cattle manure plus half rate NPK (ZC30) with net benefit of US$1336.3 ha^{-1} .Zai pits without inputs (ZNO) had the lowest net benefit of US$-16.2 ha^{-1} (Figure 4.4)). This implied that the total cost for the treatment of zai without inputs was higher than the benefits.

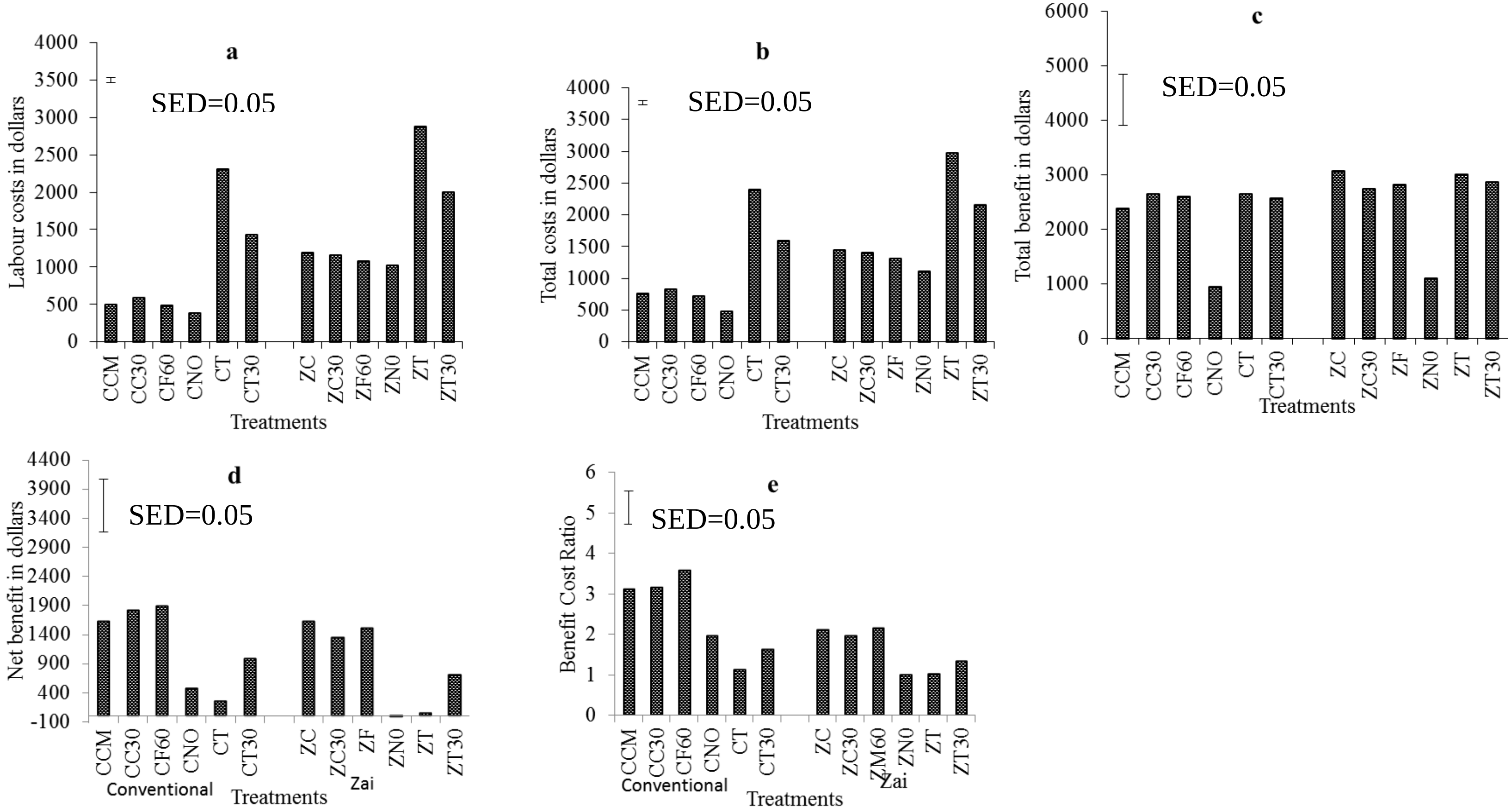

Figure 4.4: Comparison of labour cost(US dollars), total cost (US dollars), total benefit (US dollars), net benefit and BCR for three seasons SR13, LR14, SR14 under conventional and zai pit planting technique in Tharaka Nithi county a=labour cost analysis=Total cost analysis; c=Total benefit d= Net benefit e=Benefit cost ration

ZC=Zai pits +cattle manure, ZT =Zai pits +Tithonia, ZF60=Zai pits + 60 kg N ha^{-1} , ZC30= Zai pits +Cattle manure + 30 kg N ha^{-1} , ZT30= Zai pits + Tithonia + 30 kg N ha^{-1} , ZNO= Zai pits with no inputs, CCM= Conventional planting+cattle manure, CT=Conventional planting+Tithonia, CF60=Conventional planting + NPK 60 kg N ha^{-1}, CC30= Conventional planting + Cattle manure + 30 kg N ha^{-1}, CT30= Conventional planting + Tithonia + 30 kg N ha^{-1} ,CNO=Conventional planting with no inputs

Labour is the major capital input in construction of zai pits and application of soil fertility amendments. The observed trend in the three seasons was that the labour costs for zai treatments were higher ($p<0.001$) than for conventional planting techniques with the same soil fertility amendments. This could be attributed to the labour invested in digging of zai pits. These results confirm observations of other studies which report that zai technique is labour intensive (Fatodji *et al*., 2008). At the same time tithonia treated plots were also found to have had high labour costs due to the time spent on cutting and chopping of the biomass. Since tithonia was not found in the same place it took an average of three man-hours to cut the 90 kg tithonia biomass and two hours to chop the tithonia. According to ICRAF (1997), it takes about 4 minutes to collect 1 kg of fresh Tithonia biomass. Previous research has shown that application of the optimum amount of 5 tha^{-1} of tithonia requires 370 workdays per hectare while application of animal manure takes only 1–7 man-days per hectare (Jama *et al*., 1999). A study by Mucheru-Muna *et al*. (2007) reported that inorganic fertilizer gave the highest (USD12.5) return to labour while sole tithonia gave the lowest (USD 4.0). Elsewhere, Jama *et al*. (2000) observed that the labour required for collection, transport and incorporation is a major handicap to the use of large amounts of tithonia biomass. In addition, production of tithonia on an extra land has been cited as a disincentive for adoption of tithonia as a green manure (Opala *et al*., 2010).

Other Studies have valued labour at its opportunity cost (income generated during corresponding time could be spent in alternate production) (Ellis, 2000). If the alternative revenue for labour is zero due to joblessness, labour is then valued to zero (Bartik, 2011). However, in the Kenyan example it is comparatively more applicable to consider as a full opportunity cost as employment may be more likely also considering young adults have migrated to the urban centers especially in Tharaka -Nithi County (County Government of Tharaka-Nithi, 2013). Elsewhere like in the case of Burkina Faso full forgone cost for labour is unexpected due to high unemployment (Fox and Rockstrom, 2003). In case the forgone cost for labour associated with zai pit technique in combination with tithonia at respective seasons is not zero, it may prove to be the most restrictive impediment for the farmer to engage in the technology. Because of high labour requirements for cutting and applying the biomass to fields, the use of tithonia biomass as a nutrient source is more cost-effective with high-value crops such as vegetables than with relatively low-valued maize (Jama *et al*., 2000). The transfer of tithonia biomass to fields comprises the redistribution of nutrients within the land rather than a net input of nutrients.

The high total benefits obtained from zai pit technique are as result of high grain and stover yields obtained from zai pits with ammendment due to higher nutrient and water availability compared to the conventional planting technique. This implies that high total benefits from zai pits, would only be experienced when water harvested by zai pits is in combination with improved nutrient management. The high total benefits give an economic motivation as they potray high incomes for the farmers who practice these technologies. Lack of significant difference on total benefits between zai pit and conventional planting technique with no ammendments indicate that digging of zai pits will not add any monetary value without ammendments. This is consistent with observations by Zougmoré *et al*. (2004) who reported that interactions of water harvesting technologies with organic or inorganic sources of nutrients may enhance crop production and therefore be profitable to farmers.

In the three seasons, high net benefits were experienced among planting techniques with amendments except those that had been combined with tithonia. This implied that the total cost for this treatment was low and the yields were relatively high compared to other planting techniques. However, zai pit without input (ZNO) had the lowest net benefits in all the three seasons combined. This implies that it is not economically viable for farmers to use zai pits without applying any soil fertility-improving inputs. Results of the economic analysis by Mucheru-Muna *et al*. (2007) indicated that tithonia with half recommended rate of mineral fertilizer treatment recorded the highest net benefit (USD 787 ha^{-1}) while control recorded the lowest (USD 272 ha^{-1}).

The benefit cost ration was strongly affected by the labour value for the different technologies. In general, during the three seasons the BCR for zai treatments were lower than for conventional planting techniques with the same soil fertility amendments. This could be attributed to the labour invested in digging of zai pits. At the same time tithonia treated techniques had also low BCR compared to other soil fertility amendment due to the labour used on cutting and chopping of the biomass. The findings of this study are contrary to Achieng *et al*. (2010) observation that there is near to nil investment cost on the use of tithonia. On the contrary, Mutegi *et al*. (2012) reported that sole tithonia had the highest benefit cost ratio (BCR), followed closely by manure treatment. The results indicate that the yield increase with zai pits or tithonia input is not adequate to meet the high costs of labour. The income created through this activity does not pay off economically for the time invested in the digging of zai pits and application of tithonia. This contradicts Amede *et al*. (2011) report that the farm income produced by zai pits was up to 20-times higher than the labour costs required to prepare them. From the results, it can be observed that feasiblity of zai pits is dertemined by the ammendments applied. However, conventional planting in combination with organic/inorganic ammendments is more profitable than zai pits with simmilar organics or inorganic.

CHAPTER 5

SUMMARY OF THE FINDINGS, CONCLUSION AND RECOMMENDATION

5.1 Summary of findings

The findings indicate that farmer's age, years of experience, number of non-formal trainings, beneficiaries of NGOs, membership of group, wealth status and visits by non-governmental extension agents play an important role in adoption of zai pits. Other factors such as number of livestock owned by the farmer and number of groups a farmer belongs also plays a significant role in adoption and utilization of zai pits. It was also observed that very few farmers apply inorganic fertilizer on zai pits. Farmers perceived that the high economic returns of the pit to be the most significant benefit while intensive labour was deemed the most limiting in its utilization.

In general, soil fertility parameters changed with soil water conservation technique combined with various organic and inorganic resources. Cattle manure application led to a significant (p<0.05) increase in pH and nitrogen under zai pit while cattle manure plus half recommended rate NPK under zai pit treatment had a significant increase (p<0.05) in potassium and phosphorus. Conventional planting combined with half recommended rate of NPK plus cattle manure (CC30) had an increment of all the presented nutrients. Higher mean weight diameter (MWD) of soil aggregates was reported in zai pit treatments compared to conventional practice except on zai pits with no amendments which was observed to be lower than conventional planting with no inputs (CNO). The aggregate stability of zai and sole tithonia (ZT) was significantly higher (p<0.05) than conventional planting with sole tithonia (CT). Low volumetric water content (VWC) for zai treatments was observed at 5cm depth as compared to conventional treatments while high VWC was observed at the depth of 35 cm for zai treatments as compared to conventional treatments.

The zai pit as a soil water conservation technique and fertility amendments had significant ($P \leq 0.05$) effect on both sorghum grain and stover yields. The overall tendency observed was that grain yields and stover yields were higher in zai pits in combination with amendments (tithonia, cattle manure, combined organic plus inorganics and sole inorganic fertilizer) than conventional planting with significant differences ($p<0.05$) experienced mainly in treatments with organic amendments. Zai pit in combination with tithonia amendment had the highest grain yields of 4.3 $Mgha^{-1}$ in SR13 while zai pit in combination with cattle manure had the highest grain yield during LR14 and SR14 season. During the SR14, grain yields of zai pit with cattle manure (ZC) were higher significantly ($p<0.05$) by 53.7% than conventional planting with cattle manure (CCM). It was also observed that rainfall plays a very important role as far as yields are concerned. Due to the low rainfall during LR14, the yields were negligible below the lowest yields of the other seasons. Application of amendments on both zai pit and conventional planting techniques for the three seasons (SR13, LR14 and SR14) significantly ($p<0.05$) increased both the grain and stover yields compared to the control plots.

Zai pit with amendments gave the highest in total benefits as compared to conventional planting. For instance, zai pit plus cattle manure (ZC) recorded the highest total benefits followed by zai pit plus tithonia treatment. In all the three seasons labour costs were recorded highest on the zai pit plus tithonia (ZT) treatments followed by conventional planting plus tithonia (CT). This was attributed to the high labour expenditure during chopping and cutting of tithonia. Due to these costs the BCR for zai pit plus tithonia (ZT) and conventional planting plus tithonia (CT) treatment were very low as compared to other treatments. On average, conventional planting with full rate NPK (CF60) had the highest BCR (3.58) while zai pit without input (ZNO) had the least BCR of 0.94. The implication of the results is that short term application of zai pit and tithonia technologies is not as profitable as conventional planting with other amendments other than tithonia.

5.2 Conclusion

Socio-demographic characteristics of farmers such as age, years of experience, group membership and attendance of non-formal trainings were found to be significant determinants of zai pit adoption. The most common source of informationin the adoption of zai pits was non-government extension agents. Majority of the farmers who had adopted zai pits used animal manure as a soil fertility amendment. Combination of organics and inorganic fertilizers was least used as input to zai pits.

Animal manure as a soil fertility amendment increased soil pH in both zai pit and conventional practices. Organic carbon increased more in conventional treatment than in zai pit practice. Nitrogen content increased statistically under zai pit with cattle manure but declined where no amendments were applied. Soil treated with organic amendments had better aggregate stability than with inorganic fertilizers. Zai pits were observed to improve soil water moisture compared to conventional planting at the lower soil horizons. In soils where water harvesting function is not a priority compared to soil fertility enhancement function, conventional application of organic and inorganic amendments may be more suited compared to pit application of amendments

Zai pit in combination with tithonia amendment had the highest grain yields while conventional planting with no input had the lowest grain and stover yields. Grain and stover yields were observed to be signficantly higher in zai pits in combination with organic amendments than conventional practice with similar amendments. In all the three seasons the stover and grain yields for both zai and conventional practices without amendments were not statistically different.

Conventional planting with full rate NPK (CF60) had the highest BCR while zai pit without input (ZNO) had the least BCR. Conventional planting without input (CNO) had a relatively higher BCR but may not be suitable in terms of attainment of food sufficiency due to the low grain yields. Zai pits with other amendments other than tithonia had high returns to investment and could therefore be more economical to farmers with complimentary labour such as family labour so as to achieve food sufficiency.

5.3 Recommendations

Based on the findings from this study, the following recommendations were made;

1. Farmers should be encouraged to join farmer groups or association and attend non- formal training on agricultural practices to improve adoption and utilization of zai pits

2. Organic and inorganic amendments are partinent in enhancement of soil fertility in both zai pit and conventional practices. Zai pit are recommended where water harvesting is a priority

3. To enhance crop yields, both zai pit and conventional practices should be used in combination with organic and inorganic amendments in sorghum production

4. It is not economically viable for farmers to use zai pits without applying any soil fertility amendments. Farmers should be encouraged to dig zai pits during the non-peak period of labour to make the practice more profitable in production of sorghum

5.4 Further Research

- Further research on long-term studies relating to the decomposition and nutrient release rates of different types of amendments in the zai system in comparison to conventional practice is needed to understand how well nutrient release matches the crop nutrient requirements

- There is need to study the pattern of water movement in the profile in zai-treated plots and also to estimate the potential nutrient losses that can occur under these

- Further research under on-farm, farmer designed and farmer managed trials is needed to assess the economics of the zai pits in combination with selected soil fertility management options

- There is need for further economic evaluations on the performance of technologies that not only takes into account the value of the grain and stovers but also the medium to long effects that technologies may have, such as soil conservation and improvement in soil fertilityconditions

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APPENDICES

Appendix I: Farmer Interview Schedule

My name is **Serah Wairimu Kimaru** from Kenyatta University. I am interested in establishing the existence and the extent of the adoption of water harvesting and integrated soil fertility management technologies in Tharaka Nithi County. Your information is very important towards attaining this goal. The information provided will be treated with confidentiality.

Questions are addressed to the household head/farm decision maker who should preferably be the respondent.

Enumerator's Name: ________________________________

Date of interview____/_____/ 2013

Time the interview started ____ : ____

Core var. no	**Variable label**	***Variable values and rules(Where there are options tick appropriately)***
	Household Demographic and Socio-Economic Characteristics	
1	District __ __	
2	Division	
3	Location	
4	Sub-Location and village	
5	Name of the household head_	
8	Gender of household head (Decision maker of farm operations)	*1=Male 2= female*
9	Age of household head	_______________*years*

10	Educational level of Household Head?	*1=no education, 2=primary education, 3=secondary education, 4=tertiary education (Specify)*
11	How many years of farming experience______	______________*years*
12	Approximately how many non formal trainings have you attended since you started farming?____________	*1=None 2=1-5 times 3=6-10 times 4=more than 10 times*
13	Household size ________	*State the number of household members*
14	Occupation of Household head_________	*1=Farming,2=Business,3=Employed*
15	Occupation of the spouse_________	*1=Farming,2=Business,3=Employed*
16	How many household members are working on the farm?__	
17	What kind of construction materials is your house roof made of?	1= corrugated iron sheets 2= Tiles 3= Grass 4= Makuti 5= Others (Specify)
18	Are you currently a member of any farmers' group or local association in this village?	*0=No 1= Yes*
19	How many groups are you a member?	
20	What is your total farm size?	____acres
21	How much of your land is cultivated?	____acres
22	How much of your land is under pasture?	____acres
23	Is the land slopy?	*0=No 1= Yes*

24	Do you hold a formal title or registration of the whole or parts of your land?	*0=No 1= Yes*
25	How would you generally rate the fertility status of your farm? ______	*1=High, 2 = Moderate 3= Low, 4=Does not know*
26	Are you a beneficiary of any NGO program?	*0=No 1= Yes*
27	If, so which NGO?	*State*
28	How have you benefited?	*State* *1=Farming 2=Paying school fees 3=Construction of a house 4=Financial support 5=Others(Specify)*
29	Please indicate the number of livestock that you have in each category	
	i)Cattle	
	ii)Goats	
	iii)Sheep	
	iv)Donkeys	
	v)Oxen	
	vi)Hen	
30	According to the assets the farmer posses, how do you judge the wealth status of the farmer?	*1=Rich 2=Average 3= Poor*
31	Which tillage method do you use to cultivate your land	*1=Manual with hoe,2= Animal traction, 3=Tractor tillage*

32	If you use animal traction, where do you get the animal for the purpose of cultivation?	*1=own, 2= Rented 3= Borrowed*
33	Why do you do farming?	*1=for food 2=for income 3= for both income and food*
34	Have you ever received relief food?	*0=No 1= Yes*
35	Do you sell any of your farm products?	*0=No 1= Yes*
36	If so, which product?	*1= crop produce(Specify)* *2= livestock(Specify)*
37	According to you, what is the status of food security in your homestead?	*1.Not Sufficient for the family 2= Sufficient for the family 3= Sufficient for the family and Sells the suplus*
38	What do you perceive in terms of yields in your farm for the last 3 season?	*1=Increased 2= Decreased 3= No change*
39	If there is a decrease, What is the cause of the decrease?	
40	Have you ever been visited by an agricultural extension agent	
	(i) Last 1yr.	*0=No 1= Yes*
	(ii) Last 2 yrs.	*0=No 1= Yes*
41	Have you ever been visited by a non government organization officer?	
	(i) Last 1yr.	*0=No 1= Yes*

	(ii) Last 2 yrs.	*0=No 1= Yes*
42	Do you use improved planting materials	*0=No 1= Yes*
	Who makes decision on the type of technologies to adopt?	1= Husband 2= Wife 3= Joint husband and wife 4= Others
43	Do you think there are benefits in digging zai pits?	*0=No 1= Yes*
44	What benefits do you associate with use of zai pits 1. High economic return 2. Improve soil fertility 3. Less weeds - 4. Low input application such as manure or fertilizer 5. Control of soil erosion	*Score the benefits between 1 and 5 where 1=least important, 5=Very Important*

45	What challenges do you associate with use of zai pits? 1. Labour intensive 2. Difficult to maintain 3. Requires skills 4. Occupy a large portion of land 5. No immediate benefits 6. Not possible to use animal traction	*Score the challenges between 1 and 10 where 1= least challenging 5= Most challenging*

46. Which of the following water harvesting techniques are you aware of and do you practice?

water harvesting techniques	**Aware** *Indicate 0=No, 1=Yes*	**Do you practice** *Indicate 0=No, 1=Yes*	**How many years have you practiced the technology**
1=Zai pits			
2=Negarims			
3=Half moon			
4=Terraces			
5=Semi circular bunds			
6=Trapezoidal bunds			
7=Stone bunds			

8=tied ridges)			
9=Mulching			
10=others(specify)			

48. Are there any water harvesting techniques that you had started and then you dropped? *0=No 1= Yes*
49. If yes, which technology?
50. Why did you drop the technology? *1= No change of yields 2= lack of labour 3= limited land*

4=other reason (Specify)

51. Kindly fill in the following table

Water harvesting structure	**How many/long structures do you have**	**Crops grown** Crops grown 1= maize 2=sorghum 3= pawpaws 4=cow peas 5=mangoe trees 6= millet 7= Vegetables 8=green grams *(Can be more than one)*
1=Zai pits		
2=Negarims		
3=Half moon		
4=Terraces(Length)		
5=Semi circular bunds		
6=Trapezoidal bunds		

7=Stone bunds(Length)		
8=tied ridges (Length)		
9=others(specify)		

52. Which of the following soil fertility management technologies are you aware of and do you practice?

soil fertility management technologies	*Aware of*	*Practice*
i)Animal manure	*0=No 1= Yes*	*0=No 1= Yes*
ii)Green manure(specify)	*0=No 1= Yes*	*0=No 1= Yes*
iii)Application of inorganic fertilizer	*0=No 1= Yes*	*0=No 1= Yes*
iv)Combined organic fertilizers and inorganic fertilizers	*0=No 1= Yes*	*0=No 1= Yes*
v)Crop residue	*0=No 1= Yes*	*0=No 1= Yes*
Vi)Compost	*0=No 1= Yes*	*0=No 1= Yes*
Vii) Mulching	*0=No 1= Yes*	*0=No 1= Yes*
Viii)Other (Specify)	*0=No 1= Yes*	*0=No 1= Yes*

If you have been using pits on your farm kindly answer the following questions

53	When did you dig your first zai pits?	________________________
54	Who introduced you to digging of the zai pits?	*1=Government extension worker,* *2=NGO extension,* *3 = Other farmers,4=Your own experience*

55	What motivated you to start using zai pits?	*1=promotion by the NGO on cash for asset* *2=High yields obtained from the zai pits* *3=Easy to manage*
55	How many zai pits do you have?	___________________
57	Approximately how much time do you need to dig one zai pit?(in hours)	_____________________________
58	How many zai pits have you dug with the assistance of the group members?	________________________
59	How many zai pits have you dug with the assistance of the family members or alone?	________________________
60	How many zai pits did you dig this season?	_______________
	What is the spacing of the zai pits you have dug in your farm?	
61	Have you used hired labour to dig the pits?	*0=No 1= Yes*
	If yes, how much money did you pay per pit?	
62	Did you apply any animal manure on your Zai pit?	*0=No 1= Yes*
63	On approximately how many pits have you applied the manure?	

64	How much animal manure do you apply? State in terms of debes, spades, gunia, wheel barrow and others specify	
65	Do you practice crop rotation on your zai pits?	*0=No 1= Yes*
66	What had you planted the last season on your pits?	**Crops grown** 1= maize 2=sorghum 3= millet 4=cow peas5=beans 6= pigeon peas
67	What have you planted in you pits this season	1= maize 2=sorghum 3= millet 4=cow peas 5=beans 6= pigeon peas7= Green Grams 8=Others
68	Did you top dress this season?	*0=No 1= Yes*
69	If you did not top dress, why?	*1=no money to buy the inputs* *2=The fertilizer was inaccessible* *3=The crop was healthy* *4=Not aware of the need to top dress*
70	Have you experienced change of yields since you started using zai pits?	*0=No 1= Yes*
71	If yes, indicate the number of times the yields have increased	*Indicate the number of times* *1=No difference 2=one and half times* *2= Two times 3= two and half times* *4= three times 5= More than three times*

72) Which of the following technologies have you practiced? (With Zai pits)

Technology	**Tick appropriately**	**Crops grown 1= maize 2=sorghum 3= pawpaws 4=cow peas 5=mangoe trees 6= millet 7= Vegetables 8=green grams**	**How many pits?**
Zai pits + animal manure	*0=No 1= Yes*		
Zai pits + vegetation(dry or green)	*0=No 1= Yes*		
Zai pits + fertilizers	*0=No 1= Yes*		
Zai pits + animal manure +fertilizers	*0=No 1= Yes*		
Zai pits + vegetation +fertilizers	*0=No 1= Yes*		
Zai pits + animal manure+ vegetation	*0=No 1= Yes*		
Zai pits alone	*0=No 1= Yes*		

73. For the different crops how many seeds do you plant in the zai pits?

Type of crop	**No. of seeds**
Maize	
Sorghum	
Millet	
Cowpeas	
Pigeon peas	
Green grams	
Lablab(Black beans)	

74. In your own view which crops gives the highest economic returns on your farm

Type of crop	Score depending the economic returms between I and 8 where:1= is the most profitable, 8=Most profitable
Maize	
Sorghum	
Millet	
Cowpeas	
Pigeon peas	
Green grams	
Lablab(Black beans)	
Fruit trees (Specify)	

75.To what extent do you think the following challenges affect your level of production in farming?

Score between I and 10 where 1=Least challenge, 5= Highest challenge

Challenge	**Scores**
Low soil fertility	
Lack of guidance from extension agents	
Reduced access to water	
Rise in input costs	
Low rainfall	
Lack of market of agricultural produce	
Poor infrastructure	
Lack of enough land	
Expensive labour	

76.In your perception, how do you rate good agricultural practices? Score between I and 10 where 1=Most important, 5= Least important?

Good Agricultural practice	**Scores**
Less expensive inputs	
Give good economic returns	
Not labour intensive	
Does not require close supervision	
Does not require skills	
Improves soil fertility	
Friendly to livestock keeping	
Sustainable	

77. What measures do you take to secure food for your household in case of drought?

Thank you

APPENDIX II : CALCULATIONS

Total nitrogen

N concentration in soil (SNPER) (%):

$$\frac{((SNCONC - SNBLNK)\ SNVOL)}{SNSOLWT}\ 0.0001$$

where: SNCONC = N concentration in soil digest (mg/L)

SNBLNK = N concentrations in blank digest (mg/L)

SNVOL = Total volume of diluted digest (mL)

SNSOLWT = Soil/plant sample weight (g)

Organic carbon

$$\%OrganicCarbon = \frac{V_{Blank} - V_{Sample} \times M \times 3 \times 10^{-3} \times 100}{W_t}$$

Where: *VBlank*=Volume (ml) of ferrous ammonium sulphate solution required to titrate the blank

VSample=Volume (ml) of ferrous ammonium sulphate solution required to titrate the sample

Wt=*W*eight (g) of air-dry soil

3×10^{-3}=Equivalent weight of carbon

100=percentage

M=Molarity of ferrous ammonium sulphate solution (approximately 0.5M i.e. 10/Vblank).

$\%\ Soil\ Organic\ Matter\ (w/w) = 1.724\ \times \%\ Ttal\ Organic\ Carbon$--Equation 3

Total Phosphorus

The values read from the instrument are in me/100 mL of soil. The mean blank reading must be subtracted from the sample readings to obtain net concentration values.

P concentration in soil (%):

((SPCONC - SPBLNK) SNVOL) 0.0001

SNSOLWT

where: SPCONC = P concentration in soil digest (mg/L)

SPBLNK = P concentration in blank digest (mg/L)

Exchangeable Potassium

The values read from the instrument are in me/100 mL of soil. The mean blank reading must be subtracted from the sample readings to obtain net concentration values.

a) Exchangeable K (soil volume basis):

EXK100M = EXKCONC – EXKBLNK

where: EXK100M = Exchangeable K (me/100 mL soil)

EXKCONC = Concentration of K in sample (instrument reading for sample, in me/100 mL soil)

EXKBLNK = Concentration of K in blank (instrument reading for blank, in me/100 mL soil)

b) Exchangeable K (soil mass basis)

$$EXK100G = EXK100M \frac{(EXKSOLVL)}{EXKSOLWT}$$

Where: EXK100G = Exchangeable K (me/100g soil)

EXKSOLVL = Volume of extracted soil (mL)

Exchangeable Calcium and Magnesium

The values read from the instrument are in me/100 mL of soil. The mean blank reading must be subtracted from the sample readings to obtain net concentration values.

EXCA100M = EXCACONC - EXCABLNK

EXMG100M = EXMGCONC - EXMGBLNK

where: EXCA100M, EXMG100M = Exchangeable Ca and Mg (me/100 mL soil)

EXCACONC, EXMGCONC = Concentration of Ca and Mg in sample (instrument for sample, in me/100 mL soil)

EXCABLNK, EXMGBLNK = Concentration of Ca and Mg in blank (instrument for blank, in me/100 mL soil)

APPENDIX III: MOISTURE DATA COLLECTED

	LR14											
Treatment	FC		FC30		FM60		FNO		FT		FT30	
Days after sowing	5cm	35cm	5cm	35cm	5cm	35cm	5cm	35cm	5cm	35cm	5cm	35cm
10	0.19	0.13	0.21	0.15	0.22	0.16	0.21	0.15	0.23	0.10	0.19	0.16
24	0.32	0.19	0.30	0.09	0.30	0.16	0.24	0.23	0.29	0.16	0.29	0.26
38	0.20	0.15	0.13	0.08	0.21	0.10	0.18	0.17	0.16	0.08	0.18	0.16
52	0.17	0.13	0.13	0.14	0.19	0.12	0.10	0.17	0.20	0.11	0.17	0.19
66	0.15	0.10	0.12	0.15	0.14	0.11	0.12	0.19	0.14	0.10	0.10	0.21
80	0.13	0.09	0.09	0.05	0.20	0.11	0.16	0.13	0.13	0.07	0.08	0.25
94	0.22	0.08	0.16	0.06	0.33	0.08	0.16	0.06	0.19	0.10	0.22	0.22
108	0.17	0.10	0.08	0.06	0.13	0.07	0.11	0.12	0.07	0.09	0.10	0.21
122	0.22	0.11	0.14	0.08	0.16	0.13	0.13	0.09	0.13	0.05	0.16	0.22
SR14												
21	0.37	0.22	0.30	0.09	0.41	0.17	0.33	0.33	0.29	0.14	0.27	0.22
35	0.25	0.16	0.23	0.05	0.21	0.10	0.18	0.16	0.29	0.09	0.24	0.17
49	0.32	0.20	0.28	0.12	0.33	0.08	0.33	0.12	0.30	0.16	0.32	0.18
63	0.28	0.13	0.25	0.08	0.20	0.12	0.22	0.13	0.29	0.10	0.22	0.18
77	0.22	0.16	0.13	0.08	0.04	0.13	0.12	0.19	0.05	0.09	0.06	0.10
91	0.19	0.14	0.14	0.07	0.20	0.11	0.15	0.14	0.14	0.10	0.10	0.17
105	0.14	0.14	0.13	0.11	0.14	0.09	0.14	0.12	0.15	0.08	0.09	0.17
119	0.16	0.10	0.14	0.10	0.14	0.09	0.15	0.05	0.16	0.08	0.08	0.16

LR 14												
	ZC		ZC30		ZM60		ZNO		ZT		ZT30	
10	0.19	0.13	0.21	0.15	0.22	0.16	0.21	0.15	0.23	0.10	0.19	0.16
24	0.04	0.25	0.16	0.22	0.24	0.25	0.17	0.20	0.30	0.24	0.27	0.26
38	0.08	0.20	0.07	0.20	0.16	0.18	0.20	0.30	0.04	0.18	0.16	0.20
52	0.17	0.13	0.13	0.14	0.19	0.12	0.10	0.17	0.20	0.11	0.17	0.19
66	0.14	0.17	0.07	0.21	0.11	0.22	0.22	0.27	0.03	0.19	0.15	0.21
80	0.16	0.15	0.12	0.18	0.14	0.17	0.20	0.24	0.05	0.19	0.10	0.19
94	0.14	0.17	0.07	0.20	0.10	0.19	0.21	0.22	0.14	0.20	0.09	0.12
108	0.12	0.10	0.11	0.28	0.10	0.14	0.17	0.21	0.10	0.12	0.06	0.17
122	0.11	0.20	0.13	0.22	0.08	0.17	0.12	0.17	0.14	0.21	0.07	0.14
SR 14												
21	0.11	0.19	0.09	0.23	0.07	0.20	0.06	0.15	0.12	0.20	0.01	0.19
35	0.09	0.21	0.10	0.32	0.10	0.29	0.09	0.19	0.03	0.21	0.36	0.36
49	0.04	0.25	0.07	0.23	0.07	0.35	0.08	0.24	0.06	0.23	0.24	0.21
63	0.08	0.20	0.07	0.24	0.10	0.20	0.08	0.18	0.20	0.13	0.26	0.19
77	0.09	0.14	0.06	0.20	0.07	0.13	0.05	0.18	0.06	0.11	0.00	0.14
91	0.07	0.15	0.09	0.18	0.09	0.15	0.01	0.16	0.12	0.15	0.07	0.16
105	0.07	0.15	0.10	0.17	0.07	0.14	0.02	0.16	0.10	0.11	0.12	0.14
119	0.16	0.10	0.14	0.10	0.14	0.09	0.15	0.05	0.16	0.08	0.08	0.16

APPENDIX IV: RESEARCH PERMIT

THIS IS TO CERTIFY THAT:
MS. SERAH WAIRIMU KIMARU
of KENYATTA UNIVERSITY, 0-1000
Thika,has been permitted to conduct
research in *Tharaka-Nithi County*

on the topic: *EFFECTS OF WATER HARVESTING TECHNIQUES ON AGRICULTURAL PRODUCTION IN LOW MIDLAND ZONES OF THARAKA NITHI COUNTY*

for the period ending:
1st May,2015

Permit No : NACOSTI/P/14/2184/2755
Date Of Issue : 15th August,2014
Fee Recieved :USD 22.25

Applicant's Signature

Secretary
National Commission for Science, Technology & Innovation