EFFECT OF TIED RIDGES ON YIELD AND YIELD COMPONENTS OF MAIZE, SORGHUM AND DRY BEAN UNDER DIFFERENT AGRONOMIC MANAGEMENT PRACTICES IN CENTRAL KENYA

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This thesis is my original work and has not been presented for an award of a degree in any other university.

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Effect of tied ridges on yield and yield components of maize, sorghum and dry bean under different agronomic management practices in Central Kenya.

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I dedicate this work to my family who have been there for me, believing in me, encouraging and very supportive throughout the time of the study.

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LIST OF ABBREVIATIONS AND ACRONYMS

AGRA	Alliance for a Green Revolution in Africa
ANOVA	Analysis of valiance
ASAL	Arid and Semi-Arid Lands
ASTGS	Agriculture Sector Growth and Transformation Strategy
CAN	Calcium Ammonium Nitrate
CIAT	International Centres for Tropical Agriculture
FAO	Food Agriculture Organization
FAOSTAT	Food and Agriculture Organization – Corporate Statistical Database
GPD	Gross Domestic Product
GoK	Government of Kenya
IPCC	Intergovernmental Panel on Climate Change
KALRO	Kenya Agricultural and Livestock Research Organization
KARI	Kenya Agricultural Research Organization
KBA	Kenya Bankers Association
KNBS	Kenya National Bureau of Statistics
MoALF	Ministry of Agriculture, Livestock and Fisheries
NCCAP	National Climate Change Action Plan
SSA	Sub Saharan Africa
UNEP	United Nations Environmental Programme
USAID	United States Agency for International Development
THVC	Traditional High Value Crop

GENERAL ABSTRACT

The principle factors causing low productivity of food crops under rain-fed agriculture are low soil fertility, unpredictable and poorly distributed rainfall that cause low soil moisture, poor crop management practices and soil runoff. Crop production, especially in Central Kenya, is mainly reliant on rainfall which has become less reliable owing to the changes in climate. Improving water efficiency is an important first step in buffering the effects of rainfall unpredictability. However, increasing availability of water alone cannot deliver the required benefits. It is therefore, important to incorporate measures to conserve soil water with the available agronomic practices such as application of inorganic fertilizer and use of proper plant density among others to improve yields of various field crops including maize, sorghum and dry beans. This study aimed to: (i) evaluate the effect of tied ridges under different levels of N and P fertilizer on the yield and yield components of maize and sorghum; and (ii) to determine the effect of tied ridges and planting densities on growth and yield of dry bean. The two experiments were conducted at Kabete Field Station Farm of the Faculty of Agriculture, University of Nairobi during the short and long rains of 2012 and 2013, respectively. In the first experiment, the tied ridges were incorporated with combined N and P fertilizers in randomized complete block design with a split plot arrangement. Tillage practices (conventional/normal tillage and tied ridges) were allocated to the main plots and fertilizer levels (zero fertilizer, 20 kg N ha^{-1} + 40 kg P ha^{-1} and 40 kg N ha^{-1} + 40 kg P ha^{-1}) were allocated to the subplots for maize and sorghum which were planted separately and replicated three times. In the second experiment, tied ridges and varying plant densities of dry bean in a split plot design with tillage practices (conventional/normal tillage and tied ridges) assigned to the main plots and planting densities (20 cm x 45 cm, 15 cm x 45 cm and 12 cm x 45 cm) assigned to the subplots and replicated three times. Economic analysis was done using the prevailing market prices for input during the planting period and for outputs at the same time when the crops were harvested. All costs and profit were calculated on hectare basis in Kenya shillings.

Tied ridges conserved moisture during the long rains of 2013 which resulted in significant improvement of maize grain yield, maize 1000-grain weight, sorghum stovers' and sorghum panicle length. Maize yield and the weight of 1000 grains significantly increased when tied ridges were incorporated with 20 kg N ha^{-1} and 40 kg P ha^{-1} but further increase of nitrogen fertilizer to 40 kg ha^{-1} decreased the yield of maize but increased stovers' yield. Also NP fertilizer application at the level of 20 kg N ha^{-1} and 40 kg P ha^{-1} significantly ($p<0.05$)

improved grain yield of maize, panicle length and number of grains per panicle of sorghum during long rains. However, incorporating tied ridges and NP fertilizer levels had no significant effect on maize and sorghum grain yield and other parameters observed during short rains. In the second experiment of dry beans, results obtained showed that, interaction between tied ridges and plant density had a significant ($P<0.05$) effect on the yield of dry bean but not on other related parameters during long rains of 2013. Beans planted under tied ridges at a spacing of 12 cm x 45 cm (185,185 plants/ha) had higher yields than bean planted at a wider spacing of 20 cm x 45 cm. Also, plant density had a significant effect on the number of pods per plant with density of 185,185 plants/ha recording the highest number. However, interaction between tied ridges and plant density had no significant effect on the yield of dry bean during the 2012 short rains. Generally, during the short rains season higher yield of dry bean was observed under conventional tillage than under tied ridges in all plant densities with beans planted at the density of 185,185 plants/ha recording higher yield than the density of 148,148 plants/ha. Under tied ridges, plant population of 148,148 plants/ha recorded the highest yield. There was a non-significant effect on other related parameters observed including pod length, number of seeds per pod, number of pods per plant and 1000-grain weight.

In conclusion, it was found economical to incorporate tied with N and P combination at 20:40 kg ha^{-1} respectively for maize which gave the highest net profit in maize while for sorghum, conventional tillage with the same level of fertilizer registered the highest net profit. The study also showed that the highest profit was obtained in dry bean planted at a spacing of 12 cm x 45 cm (185,185 plants/ha) under tied ridges during the long rains. This was economically higher compared to the recommended spacing of 15 cm x 45 cm (148,148 plants/ha). Therefore, in Kabete region, tied ridges become effective when the rainfall is adequate but under drier conditions when the rainfall is low it is not necessary to integrate tied ridges with any combined N and P fertilizers or the plant densities studied.

CHAPTER ONE: INTRODUCTION

1.1 Background information

Agricultural sector in Sub-Sahara Africa (SSA) is one of the most important economic sectors contributing between 30-40% of the countries' GDP (World Bank, 2008). Agriculture supports more than 67% of the Sub-Saharan Africa population, especially in the rural regions. Out of the 67%, approximately 60% depend on rainfall in agricultural production (World Bank, 2015). In Kenya, 51% of the GDP is contributed by the agricultural sector directly (26%) and indirectly (25%). In addition, the sector supports livelihoods of more over 80% of the rural population through employment of more than 40% of the total population, generation of income and food security needs (GOK, 2018; ASTGS, 2018). Furthermore, agriculture generates over 65% of foreign exchange through the export earnings. An estimate of 78% of total agricultural production in Kenya is dominated by smallholder farmer owning between 0.2 and 3 hectares, under rain-fed production farming system (World Bank, 2015). Food production is mainly cultivated under rain-fed smallholder farming systems with future projections in staple food production estimated close to 90% (Rosegrant *et al*; 2002). The poor communities in the developing counties especially in Sub-Saharan Africa consume food produced majorly by the smallholder farming systems. Almost all agro-ecological zones in Sub-Saharan Africa which are equivalent to 95% of farmland in the region depends on rainfed agriculture (FAO,2017). Therefore, rain-fed agriculture is the most significant and will continue being essential in increasing food production to improve food security in Kenya.

Rainfall amounts are low and inconsistent in SSA thus food insecurity is rapidly increasing in this region. In addition, unpredictable and poor distribution of rainfall adversely limit crop production leading to low productivity (Njiru, 2009). The annual rainfall in East Africa varies from 150mm in arid and semi-arid regions to above 2000mm in the middle and highland regions (Mati, 2005). To mitigate food insecurity due to the growing population in Africa, there is need to increase crop yield by 3.3% annually (Chauvin *et al*., 2012). Agriculture in Kenya relies heavily on rain as the source of irrigation water, under rain-fed agricultural system (World Bank, 2015; FAO, 2017). The average annual rainfall in Kenya is 630mm with variations in different region. For instance, on slope of Mt. Kenya, annual rainfall is above 800mm while in the northern Kenya, less than 200mm (Amwata, D.A, 2020). In Kenya, arid and semiarid lands (ASALs) characterised by unpredictable and low rainfall at an average of 100-900 mm per annum is equivalent to 83% of the land surface. Most regions in Kenya estimated at approximately 80% receives inadequate rainfall that is not sustainable for rain fed agriculture at an average of 200mm (Njeru *et al*., 2013). The ASALs regions of Kenya which have the highest incidence of poverty and the lowest development indicator are habitat to about 10 million people constantly faced with huge food challenges (UN, 2000). It is imperative to improve the current farming practices in Kenya to mitigate shortages in food.

Food crops in Sub-Saharan Africa, and especially in the arid and semi-arid lands (ASALs) in Kenya are cultivated under rain-fed agriculture. Among the food crops, common bean (*Phaseolus vulgaris* L.), Maize (*Zea mays*) and sorghum (*Sorghum bicolor* L.) are of major importance in most communities which regard them as staple food. These crops are also regarded world-wide as significant food crops for human consumption while their residues are used for animal fodder (Broughton, 2003). Maize and sorghum are rich in carbohydrates while beans have high levels of proteins which makes the crops excellent source of dietary nutrients for the fight against hunger. These crops are produced both for subsistent and commercial purposes which generate income for the farmers. Beans assist in nitrogen fixation in the soil, while crop residue of beans, maize and sorghum after harvest is used as mulch or decomposed and used as manure to improve soil fertility (KARI, 2012).

Maize is ranked third in the world after rice and wheat as an essential food crop to mitigate food insecurity (Campus *et al.,* 2004). In addition to maize being extensively grown in Africa, it is depended upon as a main source of food by 96% of the population estimated at 300 million (Omoyo *et al.*, 2015). Consumption of maize in Kenya is estimated at 125kg per capita which provides an average of 40% calorie requirements. In Kenya it is widely grown and highly valued as a staple food crop account for over 80% of the total cereals consumed (Omoyo *et al.*, 2015). It is also a good source of income to many families (De Groote *et al.*, 2002). Therefore, successful grain production of this crop is the key to the country's food security. In Kenya, lack of maize is synonymous to food insecurity (Pingali and Pandy, 2001).

Maize is the Kenya's principle crop which rely wholly on rainfall. Despite the importance of maize in Kenya, its cultivation is limited to regions receiving enough rainfall for its production estimated to approximately 17% of the country (Onono *et al.,* 2013). Maize is extremely sensitive to water deficit especially during the critical period from flowering to the grain filling phase. During the critical period, evapotranspiration and high physiological sensitivity requires high water content which is significant in determining the main yield components of maize (Omoyo *et al.,* 2015). Maize production is characterized by high smallholders farming which contributes about 75% of overall production (KARI, 2012).

Maize is a significant crop product in various supply and value chains in Kenyan markets. Maize is used as whole grain in different dietary or as green maize. It is processed into various end products such as breakfast cereals, flour used to prepare different food like ugali and porridge, bran and cooking oil among others. In addition, maize is processed into or used as constituent of animal feeds in dairy industries (Economic review of Agriculture, 2009). Despite the great efforts made to increase maize production its consumption is over and above what is produced requiring importation of large quantities of the grain (Pingali and Pandy, 2001; Waiyaki *et al*., 2006). Many small-scale farmers obtain low yield as a result of not using fertilizers in the ratio required or the appropriate type. According to Stanley (2009), yields ranging from 1.1 to 2.5 t/ha are obtained by smallscale farmers from maize produced in absence of fertilizers or manure. Analysis of trends in maize production by Omoyo *et al*. (2015) revealed that, due to high disease and pest's incidences, low adoption of agricultural technologies and erratic changes in climate, the country is not self-sufficient to increase maize production. Therefore, studies to find suitable solutions to these challenges are necessary.

Common bean, is one of the major food crop in Kenya, second to maize and one of the most important and commonly produced pulse crop (GOK, 2006). High average consumption of common beans per capita estimated at 31.4kg/year has been reported in Africa especially in the main areas of bean production (Gichangi *et al.,* 2011). The national demand of common beans in Kenya is approximately 0.5 million metric tons per year and is increasing (GOK, 2006). Bean are significantly affordable alternative source of protein compared to animal and fish protein in many households (FAO, 2008). Moreover, common beans are easily accessible which makes them an important component in the diet for both rural and urban communities in Kenya. In addition to the high levels of quality protein in common beans, they are excellent source of vitamin B, 25-30% daily required iron levels, folic, 15% potassium and zinc, and 25% magnesium and copper important and recommended especially for the pregnant mothers (Adams, 2005: Gichangi *et al.,* 2011).

Sorghum (*Sorghum bicolor* (L.) moench), mainly grown as a rain-fed crop in semi-arid areas is one of the most important staple crops, especially for food-insecure people and the world's poor developing countries (Mwema and Mulinge, 2013). The crop is ranked fifth after wheat, rice, maize and barley among the world major cereal crops (FAO, 2008: Njagi *et al.,* 2019). Sorghum is genetically adapted to arid and semi-arid regions with hot and dry ecologies and prone to drought, where other food crops are difficult to grow (Muendi 2009). Sorghum is grown for grain and stover and provides more than 85% of all human energy.

Currently, sorghum has been reported as a staple food in more than 30 countries and depended upon by more than 500 million people (Jacquline, 2009). In most cases sorghum is used as an alternative to rice and maize. The popularity of sorghum in feeding the population in developing countries of Africa as a staple food has been out competed only by wheat, rice, maize and potatoes (Jacquline, 2009). Africa account for one-third of the global sorghum production is the largest world's producer and an average output of 70% is in the developing countries accounting for about 90% of the total area. Low yields of 0.929 metric tons per hectare have been reported for the national average sorghum grain (FAO, 2018). The potential of sorghum as a staple food in Kenya can be used to address the challenge of food insecurity, malnutrition and creation of employment to alleviate poverty. Strategies have been put in place to revitalize the crop as Traditional High Value Crop (THVC) in the growing beer market (MoALF, 2015).

The ability of sorghum to withstand periods of high temperature and resistance to drought gives it an advantage compared to other cereals (Taylor, 2003). This is especially significant in ASAL regions of Sub-Saharan Africa where most people are food insecure and other food crops like maize are unable to grow due to unfavorable environmental conditions (Muturi *et al.,* 2013). Sorghum grains ground into flour are used in preparing non-fermented and fermented porridge, brewing African traditional beer and preparing semi-leavened bread. The food product prepared from sorghum are highly nutritious, authentic and attractive with high fiber content. Furthermore, sorghum grains are also processed into animal feeds while residues from sorghum stalks are used as fodder (Muturi *et al.,* 2013). Sorghum is well adapted to drought or low rainfall, poor soils and high temperatures among other harsh abiotic factors hence suitable for growing in a wide range ecology (GOK, 2007).

However, cultivation of sorghum is extensive and characterized by low input and productivity (MacCarthy and Vlek,2012). Although high yielding varieties of maize, dry bean and sorghum have been developed, productivity of the crops under rain fed agriculture remains low due to various biotic and abiotic factors (AGRA, 2018). Examples of these factor are; volatile climatic conditions and in particular drought, low soil fertility and poor agronomic management. These features constrain food security, livelihood of smallholder farmers and the agricultural sector in general (Annon, 2010). Food security is a major threat to millions of Kenyans, with some population in the arid and semiarid regions starving due to persistent incidences of drought (NCCAP, 2012).

Productivity of these crops is mostly affected by poor climatic and soil conditions which is influenced by unpredictable rainfall patterns and drought that cause crop failure and reduced yields (Miriti *et al*., 2012). Availability of water influences demand for improved technologies that contribute to increased productivity and sustainability of agricultural systems. Potential yield of these crops is closely related to water availability (Gicheru *et al*., 2004). Although other factors such as fertilizer and good crop management can influence the performance potential of maize, dry bean and sorghum, these factors are restricted by the availability of water to the growing plants (Koochaki *et al*., 1993).

The primary soil nutrients needed for all plant growth are nitrogen, phosphorus and potassium (Sahoo et al., 2015). Among the fertilizers, nitrogen (N) is considered as the most striking nutrient element in the plant for its presence in the structure of the protein molecule. If N is used properly in conjunction with other needed soil and water management it can speed the maturity of crops such as maize and small grain hence increasing their yields (Giller *et al*., 1994). Phosphorus (P) is thought to be one of the most decisive macronutrient element required for the growth and development of plants. The plants with insufficient P limits on growth characteristics. While nitrogen is important in vegetative development, phosphorus is needed to stimulate flowering and fruit formation (Hassen *et al*., 2005; Ojo and Olufolaji, 1999). An excess of N in relation to other nutrients such as P and K can delay crop maturity (Raun and Johnson, 1995).

Plant population density also has an important effect on vegetative and reproductive development in crops especially dry bean, which can influence the number of seeds per pod and seed yield (Tetio and Gardener, 1988; Tollenaar, 1989). Maintaining correct plant population using various planting pattern has the potential to increase yield. The minimum density of plants required to achieve maximum yield is usually the optimum plant density (Lee *et al*., 2008). Determining the appropriate plant density depending on the climatic conditions is among the most important factor in gaining the highest yields (Mburu,1996).

Climate change has great impacts on agricultural production and is predicted to further worsen especially in the developing countries. This leads to reduced yields especially in crops produced under subsistence and food security crisis (Bochiolo *et al*, 2013). Unpredictable weather patterns such as prolonged and recurrent droughts, floods, severe water shortages and raised temperatures are affecting the yields of most food crops. Due to climate change, drought has become a recurrent occurrence which poses a threat to production of food crops particularly in the rain-fed agricultural system which in turn devastates vulnerable farmers (Calzadilla *et al*., 2008). Reports have indicated approximately 175.4 million ha of rain-fed agriculture that accounts for an estimate production of 440.8 MT in sub-Saharan Africa alone have been adversely affected by climate change (FAO, 2018). Further, it is reported that food security in Sub-Saharan Africa is under threat, will continue declining and could worsen in future if not properly addressed (IPCC, 2000; Ewbank, 2012).

Innovative and indigenous technologies that improve yields are necessary to improve the livelihood of people particularly smallholder farmers who depend on rain-fed agriculture (Camberlin *et al*., 2009). It is therefore important to adapt innovative interventions such as good agronomical practices such as appropriate plant density, integrated soil fertility management, rainfall and runoff harvesting systems, soil and water conservation among others (Mati, 2005).

1.2 Problem statement and justification

Food crops such as maize, beans, potatoes and vegetables are mainly grown by smallholder farmers in Kenya under monoculture or as mixed crops complemented by smaller areas of sorghum in drier parts. These crops are produced either for household subsistence or commercial in local markets (FAOSTAT, 2017; KNBS, 2000 to 2018). These crops are grown under rain-fed conditions as irrigation is generally not an alternative, as most of the smallholder farmers cannot afford it because it is costly and also in some of these semi-arid areas available water reservoirs are seasonal (Government of Kenya, 2007). Despite the great economic importance and food security of these crops, productivity has been low even though farmers adopt new technologies like improved new varieties (Chauvin *et al*., 2012). Low soil fertility, poor agronomic practices and natural resource degradation has greatly impaired agricultural productivity under rain-fed agriculture in Kenya, especially in arid and semi-arid areas (Njeru *et al* 2015).

The majority of smallholder farmers, especially in the semi-arid tropical regions, do not produce enough agricultural products to meet family requirements in most years (Molden, 2007). This is probably as a result of farmers using very low rates of inorganic fertilizers, poor crop management like spacing and population, ignorance or lack of knowledge to conserve the limited available water and other cultural practices to improve and sustain crop productivity. This has led to decline on the yields and low income in production of these food crops (Taye and Yifru, 2010). Maize, sorghum and dry bean are becoming important crops and are preferred by farmers because of their adaptability to different cropping system (KARI, 2012). They are highly adaptable to diverse agro-ecological conditions and also a good source of income to many families. Although maize, common beans and sorghum are of great economic importance in the ASAL regions of Sub-Saharan Africa, the yields continue being low under rainfed agriculture (Chauvin *et al.*, 2012).

To increase the yields of these field crops beyond the current production among smallholder farmers, there is need to improve the productivity of water which is an important first step in improving agricultural production. However, increasing availability of water alone cannot deliver the required benefit (Asfew *et al.*, 1998). Therefore, other effective agronomic practices such as appropriate use of fertilizer rates and proper plant densities are required to be incorporated with these water harvesting technologies so that land productivity and yield can be increased. Although irrigation is used to reduce water stress, water shortages and high irrigation costs often prevent irrigation to be utilized at the appropriate rates required to eliminate drought stress and the prevailing weather conditions which negatively affect food security (Oweis *et al*., 2009).

Improving the crop yields, food security and livelihood among household have required developing techniques to improve rainwater utilization and effective agronomic management (Chamberlin *et al.*, 2009). These may include use of the appropriate types and quantities of fertilizers to improve land productivity and increase yields by addressing the issue of soil moisture deficits, soil fertility stress and competition among plants. Through research a lot of effort to address the issue of soil water conservation and justifications associated with their prospect to improve water infiltration, enhance water retention in the soil and increasing yields in many field crops has been innovated (Tewodros, 2010; Njeru *et al*., 2013). Soil water conservation techniques such as crossed furrows, pitting, mulching, ripping, terraces and ridges and have successfully shown increase in yield. For example, according to Nzabi and Mutai (2004), maize had significantly higher yields when cultivated under ripping compared to ox plough in their studies carried out in semi-arid region of western Kenya. Comparably, studies carried out in Kenya by Miriti *et al*. (2005) and in Ghana by Akinyemi *et al.*, (2003) reported higher yields in ridge tillage compared to conventional. Other study has shown that use of tied ridges as water harvesting and moisture conservation have been found to be very effective and has increased yields in sorghum and millet production in Kenya (Kipserem, 2008). In Ethiopia tied ridges are traditionally used by farmers as an in-situ water harvesting technique in sweet potato production system in the eastern part of the country (Belachew *et al*., 2010). This method has been modified and extended through research to be used in increasing yields for other grains crops such as sorghum and maize (Georgis and Takele, 2000; Tewodros, 2010). There is increasing evidence that the use of poor cultural practices especially of wider spacing is also the main yield limiting factors to food crops. Population density should be adjusted to the available resources particularly soil water and nutrients. With the use of tied ridges, improvement of the yield is possible through manipulation of plant density and use of better fertilizer rate for a particular locality (Koli and Akasha, 1995).

Despite all these efforts, over 70% of ASAL communities in Kenya still live below the poverty line and are therefore prone to food insecurity and are dependent on external food aid (Amwata *et al*., 2015). Various strategies have been adapted to increase crops yields, and tied ridges as a soil and water conservation measure is among them. However, the few success cases reported require documentation to build a rich database of knowledge and information for future use by farmers and researchers to enhance development of agriculture in the region (Onyango *et al*., 2012). Limited information on the effect of tied ridges on improving yields of crops in Central Kenya has been documented. Considering the rate of growth in Kenya's population the food available for fighting hunger and poverty is still far below the requirement especially for rain-fed dependent smallholder farmers (CBS, 1999). In some cases, tied ridges when used alone as soil and water conservation technique cannot meet all the benefits of increasing crop yields but it can be enhanced if combined with improved agronomic practices. However, due to climate change effects which are affecting land productivity, some of the recommended agronomic practices like fertilizer application rates or specific planting densities for specific crops no longer hold the capacity to produce the optimum yields in a particular region. There is need to establish appropriate inorganic fertilizers and application regimes with good crop management to increase yields. Therefore, the current research was carried to identify the specific rates of fertilizer and plant density which can be incorporated with tied ridging technology to improve the yields of maize, sorghum and dry bean in Central Kenya.

1.3 Objective

The study aimed to improve maize, sorghum and dry beans productivity by focusing on soil and water conservation practices.

1.3.1 Specific objectives

1. To determine the effect of tied ridges and varying rates of Nitrogen and Phosphorous fertilizer on of maize and sorghum grain yield and yield component.
2. To evaluate the effect of tied ridges and planting density of common dry beans on yield and yield components.

1.3.2 Hypotheses

1. Tied ridges will increase yield and yield components of maize, sorghum and beans
2. Application of N and P fertilizers will increase yield of maize and sorghum
3. Increasing plant density will increase growth and seed yield of dry bean.

2.0: CHAPTER TWO: LITERATURE REVIEW

2.1 Agricultural production in Arid and semi-arid lands under rain-fed agriculture

Cultivation of crops by relying on rainfall is known as rain-fed agricultural farming system. More than a third of human population are located in Sub-Saharan Africa (SSA) of which 41% of the farm land in this region are in semi-arid areas (Mortimore *et al*, 2009). These areas are classified as unsuitable for sustainable rain fed agriculture because of the low and unpredictable rainfall patterns and high incidences of drought that lead to crop failure (Yitebetu, 2004). In Kenya, agricultural production is largely rain-fed with smallholder farmers owning between 0.2-0.3 hectares dominating the sector. Rain-fed agriculture accounts for approximately 75% and 70% of the total agricultural output and marketed produce, respectively (KBA, 2018).

In Kenya, over 80% of the country's landmass is arid and semi-arid area receiving annual mean rainfall of less than 250mm while the high potential areas suitable for rain-fed agriculture, estimated at 20% receives up to 2000mm (Amwata, 2020). The average annual rainfall received in ASALs region has the potential to support rain-fed agriculture to ensure sustainable agricultural production (Njeru *et al*., 2013). However, agricultural productivity particularly in semi-arid areas is below the potential due to unreliable rainfall, frequent droughts, floods, degraded soil and general lack of effective water management (Itabari *et al*., 2004). Agricultural productivity in Kenya is highly declining due to dependency of rains by smallholder farmers. Moreover, there has been unpredictable changes in rainfall patterns, rise in temperature and occurrences of extreme weather conditions (Amwata, 2020). Furthermore, effects of drought on agricultural productivity has been aggravated by factors such as low soil fertility, abiotic and biotic stress and poor crop management practices among others (Herufi and Yohannes, 2002). A study carried out by the International Water Management Institute to assess water use reported a high correlation between availability of water and hunger and poverty. The study further reported that effective management of rain water and soil moisture, provides an opportunity to increase productivity of food crops (Mati, 2005).

Improvement of the available farming practices is crucial in addressing the worsening food shortage crisis caused by erratic rainfall in the semi-arid regions. In recent years, several techniques for harvesting rain water have been studied to try and find a technique that is acceptable to farmers and can also increase crop yields. Results obtained after several trials show that tied ridging with combination of other agronomic practices and basins give better crop yield than other techniques (Wamari *et al.*, 2012). Among the major challenges constraining crop productivity in drier areas, low soil fertility was ranked second to water in Siaya (KARI, 1996).

2.2 Drought effects on food security in Kenya

Production of most rain fed agricultural crops especially maize, dry bean and sorghum is affected by drought (Anon 1, 2010). In recent decades, the occurrence of droughts has increased and reports have documented drought even in areas with no prior history (Amwata *et al*., 2015). The main factors influencing the occurrence and frequency of drought are; inadequate and erratic rainfall patterns, early cessation or delayed rains and long dry spells among others (Camberlin *et al.,* 2009). Drought impacts negatively on crop productivity especially in arid and semi-arid areas of Kenya which covers over 80% of the land (Kandji, 2006). Besides, drought affects availability, access, utilization and stability of food at household and country level leading to food insecurity (USAID, 2010). Important production areas of food crops such as the Central parts of Kenya are likely to decline in terms of food crop productivity and acreage under cultivation. This is considerably due to erratic rainfall pattern, over dependency of rainfall in food crop cultivation, rise in temperatures and occurrence of extreme weather (Amwata, 2020).

Smallholder farmers in developing countries particularly in Sub-Saharan Africa have numerous cases of crop failure due to drought and use of outdated farming practices. Global climatic change causing unpredictable weather patterns poses a serious threat to food security and livelihood of millions of Kenyans depending on agriculture and rain-fed production system (Amwata, 2020). Food shortage in Kenya has caused serious problems in the previous decades like the case of January 2009 where approximately 10 million Kenyan were at a risk of starvation. This led to declaration of a state of food emergency by the president of Kenya. Appeal was made to the international community for humanitarian assistance. Kenya has encountered numerous national disasters causing devastating impacts on agricultural sector due to drought since 1993 (GOK, 2018). Reports documented in the last decade have shown that Kenya is prone to drought. Additionally, studies conducted by the Intergovernmental Panel on Climate Change projected that the occurrence and incidence of drought in Kenya to intensify in the 21^{st} Century (IPCC, 2014: GOK, 2018). According to USAID (2012) projections, incidences of drought and annual precipitation during heavy rains are expected to increase (USAID, 2012).

Adaptation of technologies aimed at improving agricultural productivity under rain-fed agriculture is fundamental in increasing food security. Increased water availability to crops, improving soil moisture content and use of more effective agronomic practices which enhance efficiency in water usage is important to increase yields and food security (Critchely *et al*., 2009). Strategies to mitigate intra-seasonal dry spells that often cause crop failure and low productivity such as use of conservation tillage practices have high potential. Examples of these conservation practices include tied ridging, sub-soiling and ripping (Manyatsi *et al*., 2011). Productivity of water can be improved substantially by adapting appropriate production technologies (Critchely *et al*., 2009). To improve on rain fed agriculture, different water management technologies have been developed although their adoption has been limited (Mati, 2005). Harvesting of water optimizes management of rainfall in an integrated agricultural production system for sustainability in agriculture. This leads to up-graded rain-fed agricultural production that contributes to improved livelihood of small-scale farmers (Ibraimo, 2007; Nyangumbo *et al*., 2009).

2.3 Innovative agronomic practices which can improve crop production under rain-fed agriculture

Agronomic practices that can improve agricultural productivity under rain fed systems include harvesting of rain water, conservation tillage, water and soil conservation and management of soil fertility (Critchley, 2000). Soil water conservation involves management of water stored in the soil, creating barriers for surface runoff and trapping of rain water where it falls. Harvesting of rain water involves collecting and storage of water for future use while maximizing in-soil moisture for crop production (UNEP, 1997; Rockstrom, 2002). Rainwater is conserved within the biomass and the soil by reducing runoff and keeping the water where it falls as much as possible (Yosef *et al*., 2015). Harvesting of rain water in the fields ensures survival of food crops in the farm during the mid-season droughts and also improves soil water storage. Studies have demonstrated reduced incidences of land degradation as a result of improved soil and water management (Li *et al*., 2000; Olaleye *et al*., 2006). Tillage practices for soil and water conservation increase agricultural production and reduce the effects of low soil fertility and periodic droughts on crops in arid and semi-arid area (Liniger *et al*., 2011). In addition, mitigation of features such as surface runoff and erosion that cause land degradation through adoptions of innovative soil and water conservation technologies. Poor rainfall distribution is becoming insufficient to sustain growth and development of plants which leads to crop failure. Hence, conserving the amount of water available through water harvesting techniques is the most appropriate way of increasing crop production (UNEP. 1997).

Retaining the moisture in-situ through water harvest using various structures such as tied ridges holds water long enough and reduces runoff from the field allowing and enhancing water infiltration. In-situ conservation of soil moisture involves harvesting rain water, arresting runoff and creating barriers to hold water in the field. This improves water infiltration, utilization by plants, growth and development which contributes to increased grain yield and biomass (Ahmed *et al*., 2003). Water harvesting reduces the crop moisture stress which results to increased crop yield, food security and livelihoods among resource poor households (Nyamadzawo *et al*, 2013). According to Rockstrom (2002), water harvesting, is an old technology since modernization of agriculture in 1940s that has received little attention.

Availability of water to crop is highly enhanced through increased infiltration and reduced runoff, achieved by creating micro-basins through tillage. Some of these micro-basins that have been used in several regions of Africa include contour buds, ridging, terraces, pitting, tied ridges, earth bunds and zai pits. These practices have successfully shown an improvement in yields in many field crops (Gebreyesus and Wortmann, 2008). Olaleye *et al*, (2006) in their study reported use of Zai treatments recorded higher yield than flat planting in Niger. They further explained that, it was attributed to increased soil water holding capacity due to buildup of soil organic matter in Zai treatments. Miriti *et al.*, (2005) in Kenya and Akinyemi *et al*., (2003) in Ghana also reported greater maize yields in ridge tillage compared to conventional tillage.

2.3.1 Tied ridging technology

Tied-ridging, is a system of micro-basin tillage that involves construction of semi-permanent ridges measuring about 20-25 cm in height and spaced at regular intervals of one to two metres blocked with earth ties. These earth ties block the furrows where runoff can be prevented. Various factors such as the rate of soil water infiltration, topography of the land or slope and expected rainfall intensity are considered when constructing the tied ridging (Yitebetu, 2004). Soil moisture required for a specific crop determines selection of planting site in tied-ridging system, either on the ridges or in the furrows (Gebreyesus and Wortmann, 2008). Tied ridges increases the time and rate of water infiltration into the stirred soil by preventing run-off from the rain (Guzha, 2004). Additionally, build-up of soil moisture increases rapidly enhancing seed germination, plant growth and development (Nyamadzawo *et al*., 2008). There have been reported cases in most Sub-Saharan African countries of increased field crop yields where tied ridging has been used. For example, in northern Ethiopia, more than 40% increase in sorghum grain yield and 25% increase in soil water have been reported in tied-ridging technology compared to conventional tillage practice (Gebreyesus *et al.,* 2006). Similarly, earlier studies carried out in the Kenyan semi-arid lands have reported significant increase in crop production following the use of tied ridges as method of harvesting rain water and conserving soil moisture (Itabari and Wamuongo 2003; Gichangi *et al.*, 2007).

In Zimbabwe, tied ridges have also been used as a technique to conserve soil and water in areas where availability of mulch is limited and erosion is generally a problem (Nyakatawa, 1996). This technology has also been successfully used in crops such as cowpea and millet to improve the moisture content in the soil in Niger, Mali and Burkina Faso. Tied ridges have shown an increase in yield of about 40% in cereals compared to the flat or open ridges (Critchley, 2009). The technique has also been extensively tested and evaluated with smallholder farmers in Ethiopia, Tanzania, Uganda and Kenya (Shapiro *et al.,* 2002). Integration of tied ridges with other improved management strategies for use in soil and water conservation, in-situ results in enhanced efficiency of rain water harvest and increased crop yields. A study by Gichangi *et al,* (2007) suggested integration of in-situ soil water and rain water conservation technologies with manure for improved moisture content in the soil and crop utilization. An increase of up to 100-300% in crop yields have been reported in a study where tied ridging was used in combination with fertilizer and manure Kathuli *et al,* (2010). These practices of soil and water conservation increases efficiency of water utilization by plants even in the semi-arid regions of Kenya.

2.3.2 Effects of fertilizers on maize and sorghum production in Central Kenya

Adoption of various soil and water conservation techniques and improved agronomic practices enhances the ability of the crops to withstand harsh environmental conditions especially in the arid and semi-arid regions and also improves crop productivity (Kattumuri *et al*., 2017). In Kenyan highlands, low soil fertility associated with nitrogen and phosphorus is a limiting factor in crop production for 35-40% of farmers (Njeru *et al*, 2013). Due to these nutrient deficits, the yields of cereals and pulses especially maize, sorghum and dry bean are expected to decline if appropriate nitrogen and phosphorus fertilizers levels are not applied. Chemical fertilizers are often considered a solution to current nutrient deficiencies in soils (Chemining'wa *et al*., 2013).

Although the use of inorganic fertilizer has resulted in improved yields, several studies have indicated that added fertilizer is of no use unless sufficient water is available to support and increase plant available water (Nyangumbo *et al*., 2009). A study in the semi-arid areas of eastern Ethiopia showed that substantial yield increase was obtained from tied ridges as a water conservation practice especially where fertilizer was applied (Taye and Yifru, 2010).

Similar studies in semi-arid areas of Africa have reported increased yields of crops grown in tied ridging combined with fertilizer application as compared to tied ridging and fertilizer used singly. For instance, an increase of sorghum yield from 118 to 1071 kg ha^{-1} in crops grown under tied ridging technology combined with 50 kg ha^{-1} nitrogen fertilizer has been reported (Nyakatawa, 1996). This was in comparison to a sorghum yield increase from118 to 388 kg ha^{1} in crops grown under tied ridging technology alone. A study to investigate the use of water harvesting technologies alone and in combination with fertilizer application in semi-arid region of Kenya reported similar findings (Itabari *et al.,* 2004). This study confirmed that use of water conservation technologies such as tied ridges and zai pitting combined with application of fertilizer increased water utilization efficiency by plants and grain yield. Soil moisture profile is also improved by use of manure with either in-situ soil moisture conservation technology or otherwise (Georgis and Tekele 2000). Although the yields of many crops have been reported to increase, these yields are still far below the potential. Therefore, the first specific objective of the study is to determine the best rates of combined N and P fertilizers that can be combined with tied ridges to bring maximum yields of maize and sorghum in this region.

2.3.3 Effects of water stress and plant density on dry bean production

Growth, yield potential and plant population of dry beans is highly affected by poor climatic and soil condition (Reinchert *et al*., 2015). Inadequate soil moisture caused by unreliable rainfall and inappropriate crop density is a global threat to bean production. Crop yield of dry beans is adversely affected by soil water deficit particularly during the critical reproductive growth stage (Costa-Franca *et al*., 2000). Earlier studies have reported reduced number of flowers, pods and the number of seeds per pod due to water deficits during dry bean reproductive development (Xia, 1997).

Dry beans are highly susceptible to water stress especially during the reproductive stage of development resulting to significant yield losses (Pimentel *et al*., 1999; Nielsen and Nelson, 1998; Ramirez-Vallejo and Kelly, 1998). High yield loss in dry beans at approximately 60% have been reported due to drought ranking second after losses due to diseases (White *et al*, 1994; Singh, 1995). Occurrence of drought or water stress during the pre-flowering, flowering and post flowering stages have been reported to cause high grain yield loss in dry beans at an average of 53%, 71% and 35%, respectively (Dubetz and Mahlle, 1969).

The minimum density of plants required to achieve maximum yield is usually the optimum plant density (Lee *et al*., 2008). Consequently, maintaining correct plant population using various planting pattern has the potential to increase dry beans yield. Plant population density has an important effect on vegetative and reproductive development of dry bean, consequently influencing the number of seeds per pod and seed yield (Tetio and Gardener, 1988; Tollenaar, 1989). Planting patterns determines the plant population density which influences the rate of competition for resources such as soil nutrient, moisture and light by plants (Ihsanullah *et al*., 2002). In terms of light, plant population density affects the amount of light reaching the plants, quality and intensity which influences the growth habit of the plant and yield (Orcutt and Nilsen, 2000). Determining the appropriate plant density depending on the climatic conditions is among the most important factor in gaining the highest yields in dry bean. Bean yield increases with increased plant population density to a certain level, even though water and nutrients are not limiting factors (Mburu, 1996). Improved grain yield with increased radiation uptake is induced by distribution and dispersion of energy and light among plants due to planting pattern used (Jeffrey *et al.*, 2005; Juliana *et al*, 2001).

More than the total annual bean production in semi-arid areas of Kenya are produced by smallholder farmers under rain-fed agricultural system because use of supplementary irrigation is expensive and unaffordable (CIAT, 2004). However, bean production has remained low under rain fed agriculture production. The impacts of erratic and unpredictable rainfall due to climate change and global warming has contributed to numerous challenges faced by farmers.

Growing suitable crop cultivars and appropriate plant population density has been reported to increase yield in various annual crop species (Vega *et al*., 2001). According to Das *et al*, (1996), different optimum plant densities are required for various cultivars depending on the plant morphology to ensure full seed yield potential. A study by Pilbeam (1992) reported that interplant competition for natural resources is influenced by either plant density or the distance between adjacent plant rows or both. The study additionally reported intensified interplant competition when plant density is increased and the distance between adjacent rows remain constant. Intra species competition among plant for limited resources like nutrients due to plant population above the threshold level lead to reduced seed yield in beans. In high densities, there is competition among plants competing for CO_2, water, light and nutrients. High density also exposes plants to stress which adversely affects crop yield, quality and increases plant lodging (Cox, 1996). In the absence of irrigation and in case of water stress, some improved in-field water harvesting practices including tied-ridging enhance increase in grain yield (Hatibu *et al*., 1999; Jaetzold *et al*., 2006).

Mitigation of crop failure during dry spell period and improvement of household food security can be achieved through adoption of tied ridge technology. This technology allows for soil and water conservation and also enhances harvest of rain water for sustainable crop production (Jaffrey, *et al.*, 1991). Although farmers may use harvested water to conserve moisture, other cultural practices especially planting density on dry bean have been ignored and these has been the major yield limiting factors of bean production. Majority of the smallholder farmers assume that the adoption of high population densities will increase yields even if other factors are lacking. Thus, they believe that if you plant more seeds you will get more yields (Koli and Akasha, 1995). The improvement of crop yields through manipulation of plant density is possible. Therefore, there is need to determine the most optimum plant density for dry bean grown in tied ridges.

CHAPTER THREE: EFFECT OF TIED RIDGES AND APPLICATION OF NITROGEN AND PHOSPHORUS FERTILIZERS ON MAIZE AND SORGHUM YIELD AND YIELD COMPONENTS

3.1 Abstract

The major biophysical challenges to maize and sorghum production is poor soil fertility and inadequate water. To improve sustainable crop productivity and increase production, it is important to improve water use efficiency and incorporate with measures to improve soil fertility to address these constraints. Two experiments were conducted under rain-fed conditions during the short and long rains season of 2012/2013 to determine the effect of incorporating tied ridges and varying amount of nitrogen and phosphorus fertilizers on yield and yield components of maize and sorghum. The experiment was laid out in a randomized complete block design in a split plot arrangement and replicated three times. Tillage practices namely conventional tillage and tied ridges were allocated to the main plots and fertilizer rates; zero fertilizer, 20 kg N ha^{-1}+40 kg P ha^{-1} and 40 kg N ha^{-1} + 40 kg P ha^{-1}) allocated to the subplots. The interaction between tied ridges and N and P fertilizer resulted in significant improvement of maize grain yield and 1000-grain weight during 2013 long rains. Also sorghum panicles length was significantly improved by this interaction. This significant effect was higher when tied ridges were combined with fertilizer application at the rate 20 kg N ha^{-1} and 40 kg P ha^{-1}. Application of nitrogen and phosphorus fertilizer also had a significant effect on yields of sorghum stover and maize grain while tied ridges increased the number of maize grains per ear during long rains. However, during the short rain season of 2012, the interaction of tied ridges and N and P fertilizer application and their main effect had no significant effects on the yield and yield components of maize and sorghum. The appropriate combination rate of nitrogen and phosphorus fertilizers which gave the highest yield of maize in this study was found at 20 kg N ha^{-1} and 40 kg P ha^{-1}. These rates had the highest yield of maize when the rainfall was adequate but not for sorghum grain yield.

The results obtained from this study area showed that farmers could be advised to consider using tied ridges with 20 kg N ha^{-1} + 40 kg P ha only for $^{-1}$ maize crop when the rainfall is well distributed because they are ineffective when the rainfall is very low. For sorghum according to the study, the crop performed better under conventional tillage rather than under tied ridges hence no need to incorporate tied ridges with any level of fertilizer

applied for grain production. However, interaction of tied ridges with fertilizer at the rate of 40 kg N ha^{-1}+40 kg P ha^{-1} should be considered for stover production.

3.2 Introduction

The major staple food in Kenya is Maize, followed by sorghum which is highly adaptable to diverse agro-ecological conditions. In Kenya, they are considered as important cereals of most smallholder farmers. Maize has various uses such as consumed as roasted or boiled green maize or used as grain in food, processed into maize flour for popular meals in Kenya such as ugali and porridge, used as feed for animals and as a source of raw material.

It is the staple food crop for 96% of the population with 125 kg per capita consumption and provides 40% of the calories requirement in Kenya (Omoyo *et al.*, 2015).

Maize accounts for more than 20% of the total agricultural production and 25% of agricultural employment in the country. Maize is an important source of carbohydrate, protein, iron, vitamin B, and minerals. Its products include baked, roasted and boiled fresh maize on the cob, porridge, pastes, beer, starch, oil and livestock feed from by-products of fresh and dry maize grain (Esilaba *et al*., 2019).

The total area under maize production in Kenya is about 1.5 million hectares with annual average production estimated at 3.0 million metric tons giving a national mean yield of 2 metric tons per hectare. The yields ranges from 4 to 8 ton per hectare in high potential highlands of Kenya representing only 50% (or less) of the genetic potentials of the hybrid (Ombakho *et al.*, 2018).

Maize requires warm temperatures above 15^0C with high rainfall of 1200-2500 mm. However, it flourishes under different rainfall regions and at times tolerates annual rainfall totals between 635 mm and 1145 mm, but even adapts to semiarid regions with rainfall totals of below 380 mm (Wortmann *et al*., 2010). The optimum growth requirements of maize plants in order to exploit their inherent yield potential are a deep well-drained fertile soil, a medium to good and fairly stable rainfall pattern during the growing season. Maize plants tend to experience extreme sensitivity to water deficit during a very short critical period from flowering to beginning of grain filling phase (Omoyo *et al*., 2015). Yield potentials of maize and sorghum are essentially dependent on the amount of water, nitrogen and phosphorus supply and solar radiation.

Due to weather fluctuations, maize production in Central Kenya varies sometimes resulting in serious shortfalls. The level of production achieved by the Kenyan farmers across the major agro-ecological zones is much lower than the yield potential and has not kept pace with consumption levels over the years; thus requiring importation of large quantities of the grain (Pingali and Pandey, 2000; Waiyaki *et al*., 2006).

Sorghum (*Sorghum bicolour* L. Moench) is a cereal crop quantatively ranked the world's fifth most important cereal grain after wheat, maize, rice and barley. Africa is the largest producer of sorghum accounting for one-third of global production. The suitability and adaptability to tropical conditions prevalent in Africa explain the crops' dominance in Sub-Sahara Africa where the crop serves as viable cereal crop for the most insecure household. In Kenya, sorghum lags in importance to staple cereals such as maize, rice and wheat (Njagi *et al*, 2019). Whereas these key staples perform well in potential agricultural areas, sorghum performs well in mid to low potential agricultural areas. Majority of the sorghum produced in the country is grown in the semi-arid areas of Eastern, Western and Coastal regions (Mwema and Mulinge, 2013).

Sorghum is essential to food security (Taylor, 2003). Its ability to perform relatively well under both favorable and harsh weather conditions predominant in SSA underscore its importance. It can withstand periods of high temperature and is drought tolerant. Due to the rising trends in global warming and climate change, sorghum is a promising alternative for enhanced food and income security compared to other staples such as maize that often fall due to drought (Muturi *et al*., 2013). In Kenya, it is typically grown in marginal and semi-arid areas characterized by low and erratic rains and high temperatures (Mwema and Muringe, 2013).

Sorghum in Kenya is mainly grown by small scale farmers with farm sizes ranging from 0.4 to 0.6 Ha (1 to 1.5 acres) (KAVES, 2013). Majority of these farmers produce sorghum under the mixed farming system; intercropping sorghum with other crops such as maize, cowpeas, beans and pigeon peas (Muui *et al*., 2013). Kenya ranks last in sorghum production compared to the neighbouring countries over the past decade; Ethiopia has recorded the most significant growth in sorghum production and is productivity compares to countries in Southern and South-East Asia. On the other hand, sorghum productivity in

Kenya has stagnated over time (FAOSTAT; 2017). Kenya still imports more than one-third of the total consumption (KNBS; 2017).

The Primary soil nutrients needed for all plant growth are nitrogen phosphorus and potassium (Sahoo *et al.,* 2015). Two major constraints to maize and sorghum production are water stress due to unreliable rainfall and soil nutrients deficits especially nitrogen and phosphorus that should be addressed in order to increase their productivity in arid and semi-arid lands (Abdulahi *et al*., 2005). Moisture stress, declining soil fertility and low adoption of improved technologies such as water harvesting technologies have led to a corresponding low yields and income farmers in arid and semi-arid lands of central Kenya (Itabari *et al*., 2004). Water stress which is mostly caused by persistent incidences of drought has continued to threaten the food security situation and subjected millions of Kenyans to starvation (Njeru *et al*., 2013).

Fertilizers are sources of plant nutrient that can be The application of appropriate fertilizers is perceived as a crucial management practices that can boost the growth and development of plants in qualitatively and quantitatively (Sakakibara *et al.,* 2006). Application of fertilizer to sorghum improves yield significantly (Ashiono *et al*., 2005; Biri *et al*., 2016; Melaku *et al*., 2017). Among the fertilizers, nitrogen (N) is considered as the most striking nutrient element in the plant for its presence in the structure of the protein molecule. added to the soil to supply its natural productivity. N acts as a central role in synthesis of the plant constituents via enzymatic activities (Khalid and Shedeed, 2015). An adequate supply of N is associated with high photosynthetic activity, vigorous vegetative growth and a dark green colour. Critical leaf development stage and larger leaves would develop due to higher fertilizer application ensuring better production (Onyango *et al.,* 2022). The effect of N fertilizer depends on its rate of application, the methods and timing of application, source of N, tillage, climatic conditions and cropping system. Nitrogen supply should not be in excess or im-balanced to avoid some damage to the crop growth and production. If N is used properly in conjunction with other needed soil and water management it can speed the maturity of crops such as maize and small grain hence increasing their yields (Giller *et al*., 1994).

Phosphorus (P) is thought to be one of the most decisive macronutrient element required for the growth and development of plants. The plants with insufficient P limits on growth characteristics. Also P plays a vital role in lateral root morphology and root branching (Lopez *et al*., 2003). While nitrogen is important in vegetative development, phosphorus is needed to stimulate flowering and fruit formation (Hassen *et al*., 2005; Ojo and Olufolaji, 1999). An excess of N in relation to other nutrients such as P and K can delay crop maturity (Raun and Johnson, 1995).

In addition to use of nitrogen and phosphorus fertilizers to increase the yield of maize and sorghum, there is need for farmers to adopt appropriate soil water conservation methods to improve on the land productivity in the semi-arid areas of Kenya. Research which has been conducted in some regions such as Embu and Eastern Kenya over the years has pointed out that rainwater harvesting in combination with other agronomic practices significantly increase crop production (Njeru *et al* 2013, Mwende *et al.*, 2019). Studies in arid and semi-arid areas of Sub Saharan Africa suggested that single water conservation interventions could improve crop yields by up to 50% (Araya & Stroosnijder, 2010; Walker, Tsubo and Hensley, 2005) while combination of tied ridges and nutrient inputs have accounted for two-fold to six fold crops yields compared with conventional tillage without fertilizer use (Jensen *et al*, 2003; Zougmore *et al*., 2003). Also, according to Tewodros *et al.,* (2009), a profitable crop response to applied nutrients depends on soil water availability. Studies have also shown that lack of greater response to applied N and P fertilizer in Ethiopia was probably due to soil water deficit which is the major yield limiting factor (Tewodros *et al*., 2010). Tie-ridges might be efficient in conserving soil moisture, reducing the risk of drought stress and increasing seed yield substantially. Tied ridges allows rainwater to be retained on open furrows for longer duration as the water infiltrates thus raising the overall soil moisture retention and soil water holding capacity (Itabari, 2003; Tewodros, 2010). Previous studies have also shown that tied-ridge which is a proven method of maintaining soil moisture at 0-5 and 6-10 cm soil depth in drier periods in rain-fed agriculture increases yield by 50% (Mandumbu *et al*., 2020; Sibhatu *et al*., 2017).

The impacts of tied ridges on crop productivity vary depending on the type of crop, time of ridging, topography of the land, amount and distribution of rainfall (Gebreyesus *et al.*, 2006). Reports in Kenya have shown that soil and climatic conditions have significant effects on tillage practices used to improve rain water utilization. Sijali and Kamoni (2005) reported higher dry matter yield of 1.18Mg/ha in maize grown on tied ridges compared to flat tillage that yielded 1.04Mg/ha at 222mm rainfall. The study further reported that at 144mm rainfall, the dry matter yield was 28% less in tied ridges than in flat tillage (0.69Mg/ha). It is therefore, important to use good agricultural practices such as fertilizer application, suitable soil and water conservation practices and appropriate crop management among other to improve crop yield and to mitigate environmental challenges brought about by climate change. Moreover, studies to evaluate advantages of soil and water conservation techniques across different soil and climatic conditions are of great significance. Information on the integrated use of soil moisture conservation techniques with inorganic nutrient sources on maize and sorghum is limited. Hence, the current study aimed to explore the effects of nitrogen, phosphorous and tied ridging on maize and sorghum yield and yield components in Central region of Kenya.

3.3 Materials and methods

3.3.1 Study area

The study was carried out at Upper Kabete Campus Field Station, Faculty of Agriculture, University of Nairobi for two seasons during the 2012/2013 short and long rains. Kabete is in Kiambu County and it is located between longitude 36^0 44' E and latitude 1^0 15'S with an altitude of 1942 m above sea level (Opijah, 2000). The area has a bimodal rainfall pattern with two growing seasons per year. Long rains start from late March to June and short rains from late October to December. The average rainfall is about 1114 mm per annum with a mean annual temperature of 23.8^0C (KMD, 2000). The soil is well drained, very deep, dark reddish brown to brown-red friable humic Nitisols with good water holding capacity and aeration. The environmental condition of this area represents a wet/warmer agro-ecological zone 3 (UM3) (Kilambya *et al*., 1998; KMD, 2000). The first planting was done from October 2012 to January 2013 and the second planting from March to June 2013. Both experiments were conducted exclusively under rain-fed conditions.

3.3.2 Soil analysis

Soil samples were taken at 0-30 cm depth at the start of the experiment and at crop maturity. Soils sampled were analyzed for pH, nitrogen and organic carbon using chemical analytical techniques; Kjeldahl method for nitrogen and Walkley – Black method for organic carbon as described by Okalebo *et al. (*2002).

Table 3.1: Selected chemical properties of soil in the experiment site (0-30 cm)

Soil property	Values (at planting)	Values (at harvesting)
Ph	5.2	5.3
% N	0.17	0.25
% Organic carbon	1.66	2.36

3.3.3 Experimental treatments and design

Maize and sorghum crops were subjected to the treatments in independent experiments. The treatments for each crop comprised two tillage practices (conventional tillage and tied ridges) and three levels of fertilizer rates of nitrogen and phosphorus, (no fertilizer, 20 kg N ha^{-1} + 40 kg P ha^{-1} and 40 kg N ha^{-1} + 40 kg P ha^{-1}). The two experiments were laid out in a randomized complete block design with a split plot arrangement replicated three times. Tillage practices were allocated to the main plots (conventional tillage and tied ridges) and fertilizer levels allocated to the sub plots. Nitrogen was applied as calcium ammonia nitrate and phosphorus applied as triple super phosphate. Maize variety DK 8031 and sorghum variety KARI Mtama (drought tolerant) were used. These improved varieties were preferred because they are recommended in this agro-ecological zone where the experiment was conducted. Also they are adaptable to diverse agro-ecological zone U3 and their high potential in production hence good source of income. The main plot and subplots measured 6 m x 15 m and 6 m x 5 m respectively, for each crop. In each subplot, an area of 3 m x 4 m was designated as a sampling area where five plants were selected and tagged as the sample plants on which measurement were made.

3.3.4 Field preparation, fertilizer application and planting

The land was ploughed to a fine tilth and 5 m x 6 m plots were measured and marked out. Ridges were constructed and tied at intervals of 1 m and spaced at 30 cm between rows for the maize crop and 20 cm for sorghum for the tied-ridge treatment plots. The conventional tillage treatment plots were not ridged.

Planting furrows were made in all plots using a hand hoes at the top of the ridges. During planting no fertilizer was applied to all control plots but 20 kg N ha^{-1} as calcium ammonia nitrate and 40 kg P ha^{-1} as triple super phosphate were applied in 20 kg N ha^{-1} + 40 kg P ha^{-1}.

Then after three weeks a second split of 20 kg N ha^{-1} was applied to 40 kg N ha^{-1} + 40 kg P ha^{1} treatment plots.

Two seeds were planted per hill depending on the recommended spacing for each crop within the rows in maize and sorghum plots. Maize was planted at a spacing of 75 cm x 30 cm while sorghum was planted at a spacing of 75 cm x 20 cm. Two weeks after emergence both crops were thinned to leave one plant per hill in all plots. The trial was under rain fed conditions therefore seeds were planted a week before the onset of the rain for better germination. Weeding was done using a hand hoe to keep the plots weed free from three weeks after emergence up to tasseling for maize and panicle initiation for sorghum.

3.3.5 Data Collection

Data was collected on all of the parameters required and at physiological maturity both maize and sorghum were harvested, air dried and threshed. For maize crop, data was collected on final plant stand count at harvesting, stover yield, ear length, number of grains per ear, weight of 1000 grains and grain yield. Five sampled plants were randomly tagged per plot in a sampling area of 4 m x 3 m excluding border plants from which data was collected. Final stand count was determined by counting all the stems in the harvested area of the net plot. The length of the ear was determined by measuring its length using a ruler. The numbers of grains per ear were determined based on the five tagged plants. Grain yield was determined by harvesting all the plants in the 4 m x 3 m net plot, threshing and weighing. Samples of 1000 grains were oven dried to constant moisture content at 60^0C to determine the seed weight. Stover yield was determined by weighing above ground biomass after cutting the plants just at the surface of the soil and after harvesting and air-drying.

For sorghum crop, data was also collected on final plant stand count at harvesting, stover yield, and panicle length, number of grains per panicle, weight of 1000 grains and the grain yield. Five sampled plants were randomly tagged in each plot in a sampling area of 4 m x 3 m excluding border plants where. At harvesting time, final stand count was determined by counting all the main stems but not tillers in the harvested area of the net plot. The length of the panicles was determined by measuring the length of five sampled plants using a ruler. The numbers of grains per panicle were determined based on the five tagged plants. Then threshing was done and 1000 grains were oven dried to constant moisture content at 60^0C and weighed to determine the seed weight. Dry weight of the stover was determined by weighing above ground biomass after cutting the dry plants just at the surface of the soil and after harvesting.

Grain yield was determined based on plant harvested from the 4 m x 3 m on net plot. Grain yield/plot was converted to yield/ha.

Economic analysis was done using the usual market prices for inputs during planting period and for outputs at the same time when the crop was harvested. All costs of treatments and net profit obtained were calculated on hectare basis in Kenya shillings.

3.3.6 Determination of cost of treatment

The cost of nitrogen and phosphorus fertilizers, Bestox (pesticide), maize seeds (DK 8031) and sorghum seeds (KARI Mtama 1) were determined using the prevailing prices at the time of planting where the price of inputs was same for both seasons. Labour cost consisted of land and ridges preparation, TSP and CAN (1^{st} and 2^{nd} split) fertilizer application, planting, 1^{st} and 2^{nd} weeding, cost of spraying as well harvesting and threshing. The total yield of maize and sorghum per hectare was determined. Total cost of production (Ksh/ha) was determined by adding all cost of inputs (cost of fertilizer, pesticide, seeds) and labour.

Income (Ksh/ha) = Yield of maize/sorghum in kg*price/kg. The maize price at the time was Ksh. 30.00/kg while for sorghum was Ksh. 20.00/kg during first and second planting. Net profit was obtained from income minus total cost of production for both crops.

3.3.7 Data analysis

Data was subjected to analysis of variance (ANOVA) to evaluate the treatment effects using Genstat 15^{th} Edition statistical software (Lane and Payne, 2006). Mean separation was done using the least significance difference at p= 0.05 level of probability where the F-values were significant.

3.4 Results

3.4.1 Effect of tied ridges and combined N and P fertilizers on ear length and the number of grains per ear of maize during 2012/2013 short and long rains.

Tied ridges, fertilizer application and the interaction between tied ridges and combined NP fertilizer application levels did not significantly affect the size of the ears and number of grains per ear of maize during the short rain rains season (Tables 3.2). However, during the long rains season, tied ridges significantly ($P \leq 0.05$) increased the number of grains per ear relative to conventional tillage (Table 3.3). Generally, fewer grains per ear were observed during the short rains than during the long rains.

Stovers' yield was not significantly affected by the interaction between tied ridges and NP fertilizer applications rate during the first and second planting of short and long rains of 2012/2013 (Table 3.2). However, during the short rains of 2012, conventional tillage significantly ($P \leq 0.05$) improved stover yield as compared to yield recorded under tied ridges plots. During the long rains of 2013, fertilizer application rates significantly ($P \leq 0.05$) improved the yield of stover. The highest values were recorded in plots applied rate of 40 kg N ha^{-1} + 40 kg P ha^{-1} as compared to plots where no fertilizer was applied and 20 kg N ha^{-1} + 40 kg P ha^{-1} treatment plots (Table 3.3).

Table 3.2: Means of ear length, stover yield and grains/ear of maize as affected by tied ridges and fertilizer application effects during 2012 short rains.

	Ears length (cm)			Stover yield(kg)			Grains/ear		
Fertilizer	CT	TR	Means	CT	TR	Means	CT	TR	Means
0N+0P	10.7	10.7	10.7	21	19	20	139	130	134
20N+40P	13.8	12.1	12.9	25.6	22	23.8	190	178	184
40N+40P	11.7	10.6	112	27.3	23	25.1	168	140	154
Means	12.1	11.1		24.6	21.3		165	149	
$LSD_{P\leq0.05}$	TR=NS			TR=0.574			TR=NS		
$LSD_{P\leq0.05}$	F=NS			F=NS			F=NS		
$LSD_{P\leq0.05}$	TR*F=NS			TR*F=NS			TR*F=NS		
	CV%=18.7			CV%=18.0			CV%=20.2		

LSD: least significant difference at probability level (P) <0.05, NT=Normal tillage; TR=Tied ridges; N= kg/ha CAN; P=kg/ha TSP; F=Fertilizer; NS=Not significant

Table 3.1: Means of ear length, stover yield and grains/ear of maize as affected by tied ridges and fertilizer application effects during 2013 long rains.

	Ear length (cm)			Stover yield (kg)			Grains/ear		
Fertilizer	CT	TR	Means	CT	TR	Means	CT	TR	Means
0N+0P	12.2	14	13.1	49	58	53.5	315	332	324
20N+40P	15.3	17.4	16.3	83	113	92	319	364	342
40N+40P	15.5	15.8	15.6	115	127	121	337	323	323
Means	14.4	15.7		82	99		323	339	
$LSD_{P\leq0.05}$	TR=NS			TR=NS			TR=6.32		
$LSD_{P\leq0.05}$	F=NS			F=67.5			F=NS		
$LSD_{P\leq0.05}$	TR*F=NS			TR*F=NS			TR*F=NS		
	CV%=30.2			CV%=19.2			CV%=10.6		

3.4.2 Effect of tied ridges and combined NP fertilizers on 1000 grains weight and grain yield of maize during 2012/2013 short and long rains.

During the long rains season of 2012/2013, there was a significant effect (P≤0.05) of the interaction between tied ridges and combined N and P fertilizer on the weight of 1000 grains of maize (Table 3.5). Under tied ridges, application of N and P fertilizers at 40 kg N ha^{-1} + 40 kg P ha^{-1} (P≤0.05) significantly improved 1000 seed weight while application of 20 kg N ha^{-1} + 40 kg P ha^{-1} had no effect. The main effects of tied ridges had no significant effect on 1000 grain weight in both seasons. Tied ridges had heavier grains in the plots supplied with 20 kg N ha^{-1} + 40 kg P ha^{-1} and 40 kg N ha^{-1} + 40 kg P ha^{-1} than non-fertilized plots (Table 3.4).

The interaction between tied ridges and N and P fertilizer also had a significant effect (P≤0.05) on grain yield of maize during the long rains season (Table 3.5). In this season, tied ridges significantly ((P≤0.05) improved the yields of maize in plots applied with 20 kg N ha^{-1} + 40 kg P ha^{-1} but had no significant effect on this parameter in the no-fertilizer plots and 40 kg N ha^{1} + 40 kg P ha^{-1} plots during. Application of 20 kg N ha^{-1} +40 kg P ha^{-1} had significantly higher grain yield than application of 40 kg N ha^{-1} + 40 kg P ha^{-1} which in turn had higher grain yield than no-fertilizer control.

Tied ridges had significantly (P≤0.05) higher grain yield than conventional tillage at 20 kg N ha^{-1} + 40 kg P ha^{-1}. However, during the 2012 short rains, the interaction between tied ridges and N and P fertilizer had no significant effect ($P \leq 0.05$) on the grain yield of maize. Similarly, the main effects of tied ridging had no significant effect ($P \leq 0.05$) on grain yield.

Table 3.4: Means of 1000 grain weight and yield of maize due to tied ridges and NP fertilizer application during the short rains of 2012

	1000 seeds(g)			Grain yield(kg/ha)		
Fertilizer	CT	TR	Means	CT	TR	Means
0N+0P	280	276.7	278.3	2346	1470	1908
20N+40P	270	276.7	273.3	2998	2396	2697
40N+40P	273.3	233.3	253.3	2678	2280	2479
Means	274.4	262.2		2674	2048	
$LSD_{P \leq 0.05}$	TR=NS			TR=NS		
$LSD_{P \leq 0.05}$	F=NS			F=NS		
$LSD_{P \leq 0.05}$	T*F=NS			T*F=NS		
	CV%=12.1			CV%=22.7		

LSD: Least Significant Difference at probability level (P) $P \leq 0.05$, NT=Normal tillage; TR=Tied ridges; N= kg/ha CAN; P=kg/ha TSP; F=Fertilizer; NS=Not significant

Table 3.5: Means of 1000 grain weight and yield of maize due to tied ridges and fertilizer application during the long rains 2013

	1000 seeds (g)			Grain yield (kg//ha)		
Fertilizer	CT	TR	Means	CT	TR	Means
0N+0P	433	373	403.3	2342	2423	2382.5
20N+40P	377	436	406.7	2602	3968	3285
40N+40P	400	433	416.6	2490	3223	2856.5
Means	403	414		2478	3204	
$LSD_{P\leq0.05}$	TR=NS			TR=619.8		
$LSD_{P\leq0.05}$	F=NS			F=821.5		
$LSD_{P\leq0.05}$	TR*F=49.32			TR*F=678.0		
$LSD_{P\leq0.05}$	CV%=7.6			CV%=12.3		

LSD: least significant difference at probability level (*P*) ≤0.05, CT= Conventional tillage; TR=Tied ridges; N=kg/ha CAN; P=kg/ha TSP; F=Fertilizer; NS= Not significant;

Treatments cost

Table 3.6: Production costs (Ksh. /ha) of maize per season (1st and 2nd planting 2012/2013)

Fertilizer (TSP)	3200
Fertilizer (CAN 1st split)	1600
Fertilizer (CAN 2nd split)	1600
Maize seed (DK 8031)	1750
Land preparation	10000
Ridging	8000
Planting	5000
1st and 2nd Weeding	20000
Top dressing	4000
Harvesting and threshing	11000
Total costs of production	**66150**

The net profit obtained during short rains season was higher under conventional tillage than under tied ridges as shown in the table (Table 3.7). Under conventional tillage, the coverage net profit ranged from Ksh. 15,630/ha in no-fertilizer plots to Ksh. 30,390/ha in plots supplied with 20 kg N ha^{-1} + 40 kg P ha^{-1}. Under tied ridge plots average profit ranged from a loss of Ksh. -15650/ha under no-fertilizer to a profit of Ksh. 7330/ha in plots supplied with 20 kg N ha^{1} + 40 kg P ha^{-1}.

Table 3.7: Effect of tillage practices and NP fertilizer application on net profit/ha (Ksh.) of maize (short rains 2012)

Tillage	**Fertilizer (kg ha^{-1})**	**Grain yield (kg ha^{-1})**	**Income (Ksh../ha)**	**Prod'n cost**	**Net Profit (Ksh../ha)**
Conventional tillage	0N+0P	2346	70380	54750	15630
Conventional tillage	20N+40P	2998	89940	59550	30390
Conventional tillage	40N+40P	2678	80340	61150	19190
Tied ridges	0N+0P	1470	44100	59750	-15650
Tied ridges	20N+40P	2396	71880	64550	7330
Tied ridges	40N+40P	2280	68400	66150	2250

During the long rains season, average profit ranged from Ksh. 15,510/ha in no-fertilizer plots to Ksh. 18,510/ha in plots supplied with 20 kg N ha^{-1} + 40 kg P kg ha^{-1} under conventional tillage (Table 3.8). Under tied ridges the average profit ranged from Ksh. 12,940/ha in no-fertilizer plots to Ksh. 54,490/ha in plots supplied with 20 kg N ha^{-1} + 40 kg P ha^{-1}.

Table 3.8: Effect of tillage practices and NP fertilizer application on net profit/ha (Ksh.) of maize (long rain 2013)

Tillage practice	Fertilizer (kg ha^{-1})	Grain yield (kg ha^{-1})	Income (Ksh../ha)	Prodn' Cost (Ksh../ha)	Net Profit (Ksh../ha)
Conventional tillage	0N+0P	2342	70260	54750	15510
Conventional tillage	20N+40P	2602	78060	59550	18510
Conventional tillage	40N+40P	2490	74700	61150	13550
Tied ridges	0N+0P	2423	72690	59750	12940
Tied ridges	20N+40P	3968	119040	64550	54490
Tied ridges	40N+40P	3223	96690	66150	30540

The cumulative net profit for both seasons were higher under tied ridges where NP fertilizer was applied at the rate of 20 kg N ha^{-1} +40 kg P ha^{-1} (Table 3.9).

Table 3.9: Cumulative net profit for maize during first and second planting (2012/2013)

Tillage	Fertilizer (kg ha^{-1})	First planting net profit(Ksh./ha) (short rains 2012)	Second planting net profit(Ksh./ha) (long rains 2013)	Cumulative practice profit (Ksh./ha)
Conventional tillage	0N+0P	15630	15510	31140
Conventional tillage	20N+40P	30390	18510	48900
Conventional tillage	40N+40P	19190	13550	32740
Tied ridges	0N+0P	-15650	12940	-2710
Tied ridges	20N+40P	7330	54490	61820
Tied ridges	40N+40P	2250	30540	32790

3.4.3 Effect of tied ridges and combined N and P fertilizers on panicle's length and stovers' yield of sorghum during short and long rains of 2012/2013.

Sorghum panicles were significantly (P≤0.05) affected by combined N and P fertilizers application and their interaction between tied ridges during the long rains (Table 3.10). Panicle length of 21.8 cm in tied ridges combined with 20 kg N ha^{-1} + 40 kg P ha^{-1} was significantly (P≤0.05) higher than panicle length of 9.9 cm and 14.2 cm observed in tied ridges with no fertilizer and 40 kg N ha^{-1} + 40 kg P ha^{-1} respectively. Conventional tillage had higher panicle length than tied ridging under no-fertilizer but there was no difference in this parameter under 20 kg N ha^{-1} + 40 kg P ha^{-1} and 40 kg N ha^{-1}+ 40 kg P ha^{-1}. Combined N and P fertilizer application significantly affected the length of panicles with 20 kg N ha^{-1} + 40 kg P ha^{-1} recording the longest panicles.

During the short rain of 2012, tillage, fertilizer application levels and the interaction between tied ridges and fertilizer had no significant effect on stover yield (Table 3.10). However, during long rains of 2013 stover yield improved significantly (P≤0.05) by tied ridges and combined N and P fertilizer interaction at application of 40 kg N ha^{-1}+ 40 kg P ha^{-1}. Also, application of fertilizer alone at 40 kg N ha^{-1} and 40 kg P ha^{-1} highly increased s tover yield relatively to the no-fertilizer and 20kg N ha^{-1} application treatments (Table 3.11).

Table 3.10: Means of panicle length and stover yield of sorghum due to tied ridges and combined N and P fertilizer application effects during short rains of 2012.

	Panicle length,			Stover yield, kg		
Fertilizer	CT	TR	Means	CT	TR	Means
0N+0P	23	20.9	22	22.1	21	21.5
20N+40P	24.4	20.8	22.6	24.6	22.1	23.3
40N+40P	22.3	21.1	21.7	22	25.5	23.7
Means	23.2	20.9		22.9	22.8	
$LSD_{P<0.05}$	T=NS			T=NS		
$LSD_{P<0.05}$	F=NS			F=NS		
$LSD_{P<0.05}$	T*F=NS			T*F=NS		
	CV%=16.7			CV%=14.7		

LSD: least significant difference at probability level (P) <0.05, NT=Normal tillage; TR=Tied ridges;

N= kg/ha CAN; P=kg/ha TSP; F=Fertilizer; NS=Not significant

Table 3.11: Means of panicle length and stover yield of sorghum due to tied ridges and combined N and P fertilizer application effects during long rains of 2013.

	Panicle length (cm)			Stover yield (kg)		
Fertilizer	CT	TR	Means	CT	TR	Means
0N+0P	14.1	9.9	12	22	25.2	23.6
20N+40P	19.6	21.8	20.7	23.4	28.0	25.7
40N+40P	16.3	14.2	15.2	26.2	30.1	28.1
Means	16.6	15.3	15.9	23.8	27.7	
$LSD_{P<0.05}$	TR=NS			TR=NS		
$LSD_{P<0.05}$	F=2.21			F=2.28		
$LSD_{P<0.05}$	TR*F=2.49			TR*F=5.6		
	CV%=9.3			CV%=25.2		

LSD: least significant difference at probability level (P) <0.05, NT=Normal tillage; TR=Tied ridges; N= kg/ha CAN; P=kg/ha TSP; F=Fertilizer; NS=Not significant

3.4.4 Effect of tied ridges and combined N and P fertilizers on the number of grains per panicle, 1000 grains weight and the grain yield of sorghum during short and long rains of 2012/2013.

The number of grains per panicle was not significantly affected by tillage method and the interaction between tied ridges and combined N and P fertilizers in both seasons (Table 3.12 and 3.13). But, during the long rain season, N and P fertilizer application significantly ($p<0.05$) increased the number of grains per panicle. Application of 20 kg N ha^{-1} + 40 kg P ha^{-1} had higher number of grains per panicle than application of 40 kg N ha^{-1} + 40 kg P ha^{-1}, which in turn, had higher number of grains per panicle than no-fertilizer control plots.

Tied ridges, combined N and P and their interaction had no significant effect on the weight of 1000 grains on sorghum during short and long rains season (Table 3.12 and 3.13). The weight of the grains varied from 30 to 33 g.

Sorghum grain was not significantly affected by the main effect of tied ridges, combined N and P fertilizer levels and their interaction in both short and long rains (Table 3.12 and 3.13). Grain yield rose from 6929 kg/ha (control) to 8596 kg/ha at 20N+40P in the first season and 7398 kg/ha (control) to 8381.5 kg/ha at 20 kg N ha^{-1} +40 kg P ha^{-1} in the second season. Tied ridges and conventional tillage had average grain yields of 6907 kg/ha and 8486 kg/ha, respectively, in the short rains and 7370 kg/ha and 8380 kg/ha, respectively, in the long rain season.

Table 3.12: Means of grains/panicle, 1000 seed weight and grain yield of sorghum due to tied ridges and combined N and P fertilizer effects during short rains of 2012

	Grains/panicle			1000 seeds (g)			Grain yield (kg/ha)		
Fertilizer	CT	TR	Means	CT	TR	Mean	CT	TR	Mean
0N+0P	1102	861	982.2	30	30	30	7499	6359	6929
20N+40P	1094	770	932.4	30	30	30	9873	7319	8596
40N+40P	763	730	746.8	30	30	30	8086	7045	7565.5
Means	986.3	787		30	30		8486	6907	
$LSD_{P<0.05}$	TR=NS			TR=NS			TR=NS		
$LSD_{P<0.05}$	F=NS			F=NS			F=NS		
$LSD_{P<0.05}$	T*F=NS			T*F=NS			T*F=NS		
	CV%=23.6			CV%=12.1			CV%=42		

LSD: least significant difference at probability level (P) <0.05, NT=Normal tillage; TR=Tied ridges; N= kg/ha CAN; P=kg/ha TSP; F=Fertilizer; NS=Not significant

Table 3.13: Means of grains/panicle, 1000 grain weight and grain yield of sorghum due to tied ridges and combined N and P fertilizer effects during long rains of 2013.

	Grains/panicle			1000 grains			Grain yield(kg/ha)		
Fertilizer	CT	TR	Means	CT	TR	Means	CT	TR	Means
0N+0P	241	206	223.5	30	30	30	8154	6643	7398.5
20N+40P	520	412	466	33	33	33	8921	7842	8381.5
40N+40P	348	365	356.5	32	27	32	8065	7626	7845.5
Means	369.7	327.7		33	30		8380	7370	
LSDP<0.05	T=NS			T=NS			T=NS		
	F=112.8			F=NS			F=NS		
	T*F=NS			T*F=NS			T*F=NS		
	CV%=24.3			CV%=20.4			CV%=21.5		

LSD: least significant difference at probability level (P)<0.05, CT= Conventional tillage; TR=Tied ridges; N=kg/ha CAN; P=kg/ha TSP; F=Fertilizer; NS= Not significant

Table 3.14: Production costs (Ksh./ha) of sorghum per season (1st and 2nd planting 2012/2013)

Fertilizer (TSP)	3200
Fertilizer (CAN 1st split)	1600
Fertilizer (CAN 2nd split)	1600
Pesticide	2400
Sorghum seed (KARI Mtama 1)	4000
Land preparation	10000
Ridging	8000
Planting	7600
1st and 2nd Weeding	18000
Spraying	3600
Top dressing	2000
Birds Scaring	22400
Harvesting and threshing	12000
Total costs of production	**96400**

During the short rain season of 2012, the net profit obtained for sorghum was higher under conventional tillage as compared to tied ridges. Under conventional tillage, profit ranged from Ksh. 64,980/ha when no-fertilizer was applied to Ksh. 107,660/ha when 20 kg N ha^{-1} + 40 kg P ha^{-1} was applied which was the highest profit obtained. Under tied ridges, profit ranged from Ksh. 37,180/ha when no-fertilizer was applied to Ksh. 51,580/ha when 20 kg N ha^{-1} + 40 kg P ha^{-1} was applied (Table 3.15).

Table 3.15: Effect of tillage practices and NP fertilizer application on net profit/ha (Ksh.) of sorghum (short rains 2012)

Tillage (kg ha^{-1})	Fertilizer (kg ha^{-1})	Grain yield (Ksh../ha)	Income (Ksh../ha)	Cost (Ksh../ha)	Profit practice
Conventional tillage	0N+0P	7499	149980	85000	64980
Conventional tillage	20N+40P	9873	197460	89800	107660
Conventional tillage	40N+40P	8086	161720	91400	70320
Tied ridges	0N+0P	6359	127180	90000	37180
Tied ridges	20N+40P	7319	146380	94800	51580
Tied ridges	40N+40P	7045	140900	96400	44500

During the long rains season, sorghum planted under conventional tillage in all applications of N and P provided the highest average net profit relative to the one planted under tied ridges. Highest profit obtained was Ksh. 88,620/ha under conventional tillage at 20 kg N-1 +40 kg P-1 while under tied ridges highest profit was Ksh. 62,040/ha with the same level of NP fertilizer (Table 3.16).

Table 3.16: Effect of tillage practices and NP fertilizer application on average profit/ha (Ksh.) of sorghum (long rains 2013)

Tillage practice	Fertilizer (kg ha^{-1})	Grain yield (kg ha^{-1})	Income (Ksh./ha)	Cost (Ksh./ha)	Profit (Ksh../ha)
Conventional tillage	0N+0P	8154	163080	85000	78080
Conventional tillage	20N+40P	8921	178420	89800	88620
Conventional tillage	40N+40P	8065	161300	91400	69900
Tied ridges	0N+0P	6643	132860	90000	42860
Tied ridges	20N+40P	7842	156840	94800	62040
Tied ridges	40N+40P	7626	152520	96400	56120

The cumulative profit obtained was higher on sorghum planted on conventional tillage plots where fertilizer was applied at 20 kg N ha^{-1} + 40 kg P ha^{-1} as compared to plots under tied ridges with all levels of fertilizer (Table 3.17).

Table 3.17: Cumulative net profit (Ksh./ha) of sorghum for two seasons short and long rains 2012/2013

Tillage practice	Fertilizer (kg ha^{-1})	First planting/SR net profit(Ksh./ha)	Second planting/LR net profit(Ksh./ha)	Cummulative net profit
Conventional tillage	0N+0P	64980	78080	143060
Conventional tillage	20N+40P	107600	88620	196220
Conventional tillage	40N+40P	70320	69900	140220
Tied ridges	0N+0P	37180	42860	80040
Tied ridges	20N+40P	51580	62040	113620
Tied ridges	40N+40P	44500	56120	100620

3.5 Discussion

Soil moisture stress and low soil fertility are major limiting factors to plant growth and yield (Yordanov *et al.,* 2000). Failure to meet the full crop requirements may lead to development of water deficit which in turn affects crop growth and yield. Individual grain weight in most grain crops is commonly analyzed as the product of the individual grain growth rate by duration of grain filling. Soil and water conservation practices such as tied-ridges have been reported to potentially improve yield of grain crops. The beneficial effects of tied-ridges on crop yield can vary with the amount and distribution of rainfall, cropping system and fertilizer applications.

From this study, the results showed that during the first planting of short rains 2012, there was no significant effect on interaction between tied-ridging and combined N and P fertilizer levels on the parameters observed on maize and sorghum. Yield and yield components of maize and sorghum were not significantly affected by the treatments combinations. This could be probably associated with reduced soil moisture content as a result of low rains. During this season, the amount of rainfall received was low as compared to long rains. At grain filling stage of maize and sorghum crops, the rain ceased within weeks. As a result of this drier period, this could have resulted to water stress which affected the crops hence to the low yields observed especially where tied ridges were used which was shown on low yield recorded on maize and sorghum compared to one recorded under conventional tillage (Table 3.4 and 3.12). This low yields especially under tied ridges could be attributed to the low amount of rainfall hence little water was harvested by tied ridges. Besides, the tied ridges could have exposed the soil to evaporation hence the soil dried faster compared to conventional tillage where soil was less disturbed. The results of the study are in agreement with the findings of Gicheru *et al,* (2004), working in the marginal areas of Laikipia district Kenya, which reported that tied ridging conserved the lowest amount of moisture when the rainfall was low compared to conventional method where soil was less disturbed and this could have attributed to high evaporation losses due to increased soil surface exposure hence low yields.

In the second planting of long rains 2013, tied ridges and combined 20N+40P fertilizer levels significantly increased maize grain yield, 1000 grain weight of maize, stovers yield as well sorghum panicles length. During this season, the amount of rainfall received was slightly higher as compared to one received during first planting of short rains. Higher maize grain yields could be probably due to tied ridges which could have retained more water compared to conventional tillage and this gave more time for the harvested water to penetrate and infiltrate hence enabling the maize plants to use water that could have been lost as runoff hence utilizing the available nutrients supplied by N and P fertilizers. Water harvested may have been retained in the ridges enhancing rapid build-up of soil moisture needed during reproductive stages of the plant and these could have helped the crop during grains filling resulting to higher yields observed in this season. These results are in agreement with the findings of Asfew *et al,* (1988) and Heluf *et al*, (2003) who reported increased yields of maize when tied ridges were combined with N and P fertilizers and planting methods on two soil types. This study also showed that NP fertilizer had effect on grain yield and these results agreed with the report of Fernandez *et al* (1959) and of Abdulahi *et al,* (2005) who reported that addition of nitrogen fertilizer results in large increase on yield for all varieties of crops. Also heavier 1000 seed weight observed under tied ridges could have been attributed to the larger volumes of seeds due to larger accumulation of assimilates. These results could be in agreement with Alemayehu (1995) who suggested that the main reason for decreased seed weight could be due to reduction in supply of assimilates both at anthesis and grain filled process.

Higher yield of stovers of maize and improved sorghum panicles was observed in treatment combinations of 40 kg N ha^{-1}+40 kg P ha^{-1} under tied ridges compared to other treatments. These results could have been attributed by improved soil moisture observed during long rains from higher rainfall received. As a result, nitrogen was readily absorbed and taken up by the plant which facilitates development of leaf area and lateral stem. When nitrogen is applied to crops, it improves plant growth by increasing plant height and stem diameter thus enhancing leaf expansion and development (Okpara, 2000). In addition, nitrogen plays a key role in vegetative growth because it is involved in protein synthesis which promotes plant growth (Hassan *et al*., 2010). Akintoye (1996) also reported that addition of nitrogen fertilizer increased plant height. Increase in plant height resulted in an increase in leaf number per plant hence increase stovers yields. This is in agreement with Gasim (2001) who indicated that increase in plant height increases the number of internodes and length of the internode which result in progressive increase of stovers yield. Similarly, Abdel-Mawgoud *et al*., (2005) reported positive effect of nitrogen element on plants growth that leads to progressive increase in internode length and consequently increase in plant heights. These results also agree with the findings of Adeleke and Haruna (2012) and Onyango *et al*, (2022) who reported significant response of maize leaf as a result of nitrogen application and larger leaves would develop due to higher fertilizer application ensuring better production. Several investigations had also revealed that above ground biomass and grain yields increased with application of increasing levels of phosphorus fertilizer (Walia *et al*., 1980; Kumar and Rao, 1992).

Sorghum grain yields observed was low under tied ridges in both seasons but higher yield under conventional tillage in both seasons. During short rains of 2012, low yields observed could have been attributed by no available water harvested by the ridges due to low rainfall received hence low soil moisture conserved. Also construction of tied ridges could have exposed the soil for evaporation hence the soil dried faster compared to conventional tillage where soil was less disturbed as reported by Gicheru *et al* (2004) that tied ridging conserved lowest amount of soil moisture when the rainfall was low as compared to conventional tillage. Similarly, low yield was observed under tied ridges during long rains even if rainfall was higher. This could be as result of poor seed germination and seedlings establishment at early growth stage which might be caused by excessive soil moisture as result of water logging harvested by tied ridges. Sorghum crop under conventional tillage produced higher yield in both seasons with highest observed in 20N+40P fertilizer application rate.

In conclusion, results obtained from this study area showed that farmers could be advised to consider using tied ridges with 20 kg N ha^{-1} + 40 kg P ha^{-1} only for maize crop when the amount of rainfall is high because they are ineffective when rainfall is low. Also tied ridges were not effective for sorghum grain production either when rainfall is high or low. However, in these area farmers may not need to use tied ridges to improve sorghum production but the crop performs better under conventional tillage.

Economically, the cumulative net profit obtained from sorghum production was higher under conventional tillage as compared to tied ridges while highest profit on maize was obtained from maize under tied ridges and the highest profit was obtained during long rains under conventional tillage with NP fertilizer at 20 kg N ha^{-1}+40 kg P ha^{-1}. According to this study it is not necessary to institute tied ridges with any studied levels of NP fertilizers for sorghum grain production in either short or long rains season.

CHAPTER FOUR: EFFECT OF TIED RIDGES AND PLANTING DENSITY ON YIELD AND YIELD COMPONENT OF DRY BEAN AT KABETE, CENTRAL KENYA

4.1. Abstract

Dry bean (*Phaseolus vulgaris* L.) has a great potential for improving human nutrition due to its high protein content. However, moisture stress due to low rainfall and poor crop management practices has been found to be one of the major limiting factors to dry bean production. A field study was carried out to determine the effect of tied ridges and three varying plant densities on yield and yield components of dry bean at the University of Nairobi field Station during 2012/2013 short and long rains season. The experiment was laid out in a randomized complete block design in a split plot arrangement with three replications. Two tillage practices (conventional tillage and tied ridges) were allocated to the main plots and three varying densities (111,111 plants/ha, 148,148 plants/ha and 185,185 plants/ha) were allocated to the subplots. The results obtained from the study showed that the interaction between tied ridges and plant density had no significant effect on yield and yield component of dry bean during the short rain season of 2012. Plant density had a significant effect on the number of pods per plant with density of 185,185 plants/ha recording the highest number of pods per plant. Generally, during the short rains higher yield of dry bean was observed under conventional tillage than under tied ridges in all plant densities with bean planted at the density of 185,185 plants/ha recording higher yield than population of 148,148 plants/ha and 111,111 plants/ha. Under tied ridges, plant population of 148,148 plants/ha recorded the highest yield. There was non-significant effect on other related parameters observed including pod length, seeds per pod, pods per plant and 1000-grain weight. However, during the long rain season of 2013, the interaction between tied ridges and plant density had a significant ($P<0.05$) effect on the yield of dry bean but not on other related parameters observed. Beans planted under tied ridges at a higher population of 185,185 plants/ha significantly had higher yields than bean planted at population of 148,148 and 111,111 plants/ha.

From the study, it was found unnecessary to incorporate tied ridges with any plant density studied during the short rains season when the rainfall was not adequate but farmers from this region should consider using tied ridges with a spacing of 45 cm x12 cm of dry bean when the rainfall is moderately distributed.

4.2 Introduction

Common dry bean (*Phaseolus Vulgaris* L.) is the most widely cultivated legumes in the world. It is grown in 128 countries and territories on more than 27 million hectares across the world. Sub-Saharan Africa accounts for about 16% of the total world common bean production (Esilaba *et al*., 2021). Tanzanian, Kenya and Uganda are the largest producer in SSA. Kenya has the largest area but Tanzania produces more because of its better yields (662 kg/ha as opposed to 471 kg/ha for Kenya) (Esilaba *et al*., 2021). Kenya is the seventh biggest producer globally and the second leading producer in East Africa (KenIvest, 2016). Common bean ranks second to maize in its importance as a food crop and are cultivated almost exclusively by about 1.5 million smallholder farmers on about a million hectares with yields of about 0.6m T/ha. National consumption is assessed to be about 755000 metric tonnes (T) annually against a production of about 600000 metric tonnes (T) a year per capita. In Kenya per capita consumption is estimated at 14 kg per year but can be as high as 66 kg per year in the western region (Kenivest, 2016; Esilaba *et al*., 2021).

The crop is mainly grown by smallholder farmers in the high and medium rainfall areas with fewer than five acres and mostly intercropped with maize although in semi-arid lands, it is grown with additional rainwater harvesting. They play an essential role in the sustainable livelihoods of smallholder farmers and their families by providing both food security and income generation (Muui *et al*, 2007; CIAT, 2014). Nutritionists characterize the dry bean as a nearly perfect food because of its high protein content and generous amounts of fibre, complex carbohydrates and other dietary necessities. It serves as a cheap source of cholesterol-free proteins. Dry bean is also associated with *Rhizobium* and fixes atmospheric nitrogen in the soil (Katungi *et al*., 2010). Fixation of atmospheric nitrogen improves the soil nitrogen level benefiting the followed crop, which reduces production costs (Esilaba *et al.*, 2021). If dry bean residues are left on the field they improve both the soil structure and texture (Barrett, 1990).

More than the total annual bean production in semi-arid areas of Kenya are produced under rain-fed agricultural system because use of supplementary irrigation is expensive and unaffordable (CIAT, 2004). However, bean production has remained low under rain fed agriculture production. The impacts of erratic and unpredictable rainfall due to climate change and global warming has contributed to numerous challenges faced by farmers (Mburu, 1996).

Dry bean grown under rain-fed systems may face several problems. They have a poor reputation both in terms of yield potential and tolerance to physiological stresses such as moisture stress. Water stress caused by drought and inadequate irrigation capacity is a global threat to bean production especially in developing world (ECABREN, 2000; Buruchara, 2007). Periods of water stress during the reproductive phase of the common bean cause significant reduction in grain yield. The decrease in grain yield results from a low percentage of fruit production from flowers when drought occurs during flowering and from embryos abortion when it occurs in the pod-forming stage (Pimentel *et al*., 1999; Ramirez-Vallejo and Kelly, 1998).

Drought stress results in significant reduction in seed yield in about 60% of the total global bean producing areas (Graham and Ranalli, 1997; Rosales-Serna *et al*., 2004). Extreme weather conditions such as insufficient or unpredictable rainfall will make local crop production impossible and subject about 49 million at a risk of hunger by 2020 (Jarvis, 2009). Even if high yielding drought resilient cultivars of bean that use water more efficiently thus reducing dependence on expensive irrigation water to improve production have been developed (Griffiths *et al*., 2002), this is not enough to cope with harsh condition in arid and semi-arid lands agricultural production.

Mitigation of crop failure during dry spell period and improvement of household food security can be achieved through adoption of tied ridge technology. This technology allows for soil and water harvesting and storage thus enhancing utilization of nutrients by the plant for sustainable crop production (Jaffrey, *et al.,* 1991). Although farmers may use tied ridges to harvest water, other cultural practices especially use of proper planting density for optimum yield on dry bean have been ignored and these has been the one of the major yield limiting factors of bean production.

The optimum sole-crop density for beans varies according to growth habit. The total density that can be sustained also depends on environmental resources available and under conditions of water stress, it is usually suggested that plant density be low. The current plant spacing (45 cm x 20cm) for beans which has been recommended is no longer sustaining high yields as required and therefore the best yields of beans may arise from planting population that will minimize inter and intra-row competition depending on the available moisture (Adams, 2005).

Increase in yield can be ensured by maintaining appropriate plant population of different planting patterns. The optimum plant density refers to the minimum density of plants required to obtain maximum yields (Lee *et al.,* 2008). Studies with several bean species have shown that yield can be increased by growing appropriate cultivars at extremely high plant densities (Adams, 2005) but Kwapata and Hall (1990) stated that cultivars with different morphologies would require different optimum densities to express their full seed yield potential. In several types of bean, high densities have been associated with pest outbreaks, diseases and shedding of leaves. Under high plant densities majority of bean plants become too thin, less vigorous and increase in height resulting in lodging due to high competition between plants (Al-Rifaee *et., al*., 2004; Bakry *et al*., 2011). Low light intensity during high plant population causes less radiation interception which consequently results in reduced photosynthetic efficiency and reduced number and quality of bean pods (Worku *et al*., 2004). Usually it is suggested that under stress conditions of drought and low soil fertility, farmers' plant at low density and when there is adequate moisture, very high plant densities are sometimes used by farmers who argue that more plants are needed to fill the available space because of the available resources rotation (Orcutt and Nilsen, 2000).

Growing suitable crop cultivars and appropriate plant population density has been reported to increase yield in various annual crop species (Vega *et al*., 2001). According to Das *et al*, (1996), different optimum plant densities are required for various cultivars depending on the plant morphology to ensure full seed yield potential. A study by Pilbeam (1992) reported that interplant competition for natural resources is influenced by either plant density or the distance between adjacent plant rows or both. The study additionally reported intensified interplant competition when plant density is increased and the distance between adjacent rows remain constant. Intra species competition among plant for limited resources like nutrients due to plant population above the threshold level lead to reduced seed yield in beans. In high densities, there is competition among plants competing for CO_2, water, light and nutrients. High density also exposes plants to stress which adversely affects crop yield, quality and increases plant lodging (Cox, 1996). The improvement of crop yields through manipulation of plant density is possible.

Rain water harvesting has played an important role in improving agricultural production under rain-fed agriculture. It is an important task to increase agricultural productivity as it provides water in drought prone area for supplementary irrigation when rains stop early (Getaneh *et al.,* 2013). Water harvesting technologies for improved water use efficiency have been evaluated in several semi-arid regions in the country (Sijali and Kamoni, 2005). In East Africa, interest in soil water conservation is growing rapidly as more people are beginning to realize that water harvesting is important and it can be used for sustainable crop production (Bayu *et al*., 1998). Several national and international bodies have launched programs to investigate the potential of water harvesting but it is well recognized that much had to be done to clearly identify their real capabilities in several environmental conditions.

Dry bean is primarily cultivated as sole crop, intercropped with cereals or planted in with none legume crops for soil fertility improvement. The preferred planting practices for beans are either sole cropping or rotations due to climate change which is contributing to increased frequency in droughts and hence inadequate soil moisture for bean intercropping. Consequently, the crop has been poorly managed where farmers do not use any specific planting densities or fertilizer (Katungi, 2009). This improvement of yields through manipulation of plant density is possible. This can be done by adjusting plant population to the available resources particularly soil water and nutrients to improve water use efficiency. Generally, information on plant population and yield performance relationship is still limited and majority of farmers still cultivate bean under traditional planting methods, yet there is limited information on appropriate planting methods to be adopted by these bean farmers (Musana *et al*., 2020). Adoption of suitable and optimum spacing would fulfil the objective of maximizing the yield of dry bean. Although altering plant densities to optimize crop yield has been well studied (Mburu, 1996; Pachico, 1993) the effects of altering plant population density under tied ridges have not been taken into much consideration. Therefore, the objective of this study was to determine the performance of dry bean on yield and yield components as influenced by tied ridges and different plant densities.

4.3 Materials and methods

4.3.1 Study area

The experiment was conducted for two seasons at Upper Kabete Campus Field Station, University of Nairobi in Central Kenya. Kabete is located between longitude 36^0 44' E and latitude 1^0 15'S with an altitude of 1942 m above sea level (Opijah, 2000). The site has a bimodal distribution of rainfall with two growing seasons per year (short and long rains). The long rain season is between April and May while the short rain season is between October and December. The average rainfall is about 1114 mm with a mean annual temperature of 23.8 ^{0}C (KMD, 2000). The soil is well drained humic Nitisol with good aeration and water holding capacity). The first planting was done from October 2012 to January 2013 and the second planting from March to June 2013. The experiment was conducted exclusively under rain fed conditions.

4.3.2 Experimental design and treatments

The experiment was laid out in a randomized complete block design in a split plot arrangement with three replications. The treatments consisted of two tillage practices (conventional tillage and tied ridges) and three planting densities: 45 cm x 20 cm (111,111 plants/ha), 45 cm x 15cm (148,148 plants/ha) and 45 cm x 12 cm (185,185 plants/ha). The spacing of 45 cm x 20 cm was used as a control treatment as it was a recommended spacing of bean at the time in Kenya. The tillage practices were allocated to the main plots and the plant densities to sub plots. Each main plot measured 30 m x 6 m while each subplot measured 5 m x 6 m. In each subplot, an area of 3 m x 4 m was designated as a sampling area and five plants from this area were selected and tagged.

Kakamega bean 8 (K8) is an improved variety with a potential of high yielding and adaptable to diverse agro-ecological zone U3 which is upper midland 3. Also the variety is resistant to fungal diseases of bean hence preferred by most farmers.

4.3.3 Field preparation, planting and crop husbandry

The land was ploughed to a fine tilth and plots each measuring 5 m x 6 m were marked out. Ridges were constructed and tied at the intervals of 1 m and spaced at 45 cm between rows in three plots per block while control plots conventional tilled plots were left undisturbed. Planting furrows were made at the top of the ridges using a hand hoe. During planting, 20 kg N ha-1 calcium ammonia nitrate (CAN) and 40 kg P /ha triple super phosphate (TSP) were applied uniformly in the furrows to all treatments. Two seeds were planted per hill in each plot and thinned two weeks after emergence to leave one plant per hill. Hand weeding was done twice to all plots. The first weeding was done three weeks after emergence and the second weeding was done three weeks later before flowering. Bestox® (active ingredient alphacypermethrin) was sprayed to the crop at flowering stage to control aphids.

4.3.4 Data Collection

The parameters measured included: Days to 50% crop emergence, biomass, number of pods per plant, pod length, seeds per pod, 1000 grain weight and grain yield. The number of plants that had emerged was counted daily from 7 days after planting and days to 50% emergence was estimated in each plot.

Thinning was done to leave one plant per hill. At thinning, five plants were randomly selected for biomass determination. Shoot biomass was determined by weighing the fresh shoot with a weighing balance and the weight determined. The stems and leaves were then separated and put in khaki pollination bags, oven dried at 60^0C to a constant weight and dry weight determined. At 50% flowering, all the leaves were counted from the five tagged plants in each plot and recorded. Plant height was determined by measuring the height of each of the five tagged plants from the base of the plant to the tip of the last leaf.

At physiological maturity, the number of pods per plant, pod length and number of seeds per pod was counted recorded from the selected tagged five plants from each plot. The crop was harvested from an area of 1 m x 1 m, air dried, threshed and weighed. Also the weight of 1000 seed from selected tagged plant was taken. Grain yield/plot was converted to yield/ha. Economic analysis was done using the usual market prices for inputs during planting period and for outputs at the same time when the crop was harvested. All costs of treatments and net profit obtained were calculated on hectare basis in Kenya shillings.

4.3.5 Determination of cost of treatment

The cost of TSP and CAN fertilizers, seeds, Bestox and Antracol (pesticide and fungicide) were determined using the prevailing prices at the time of planting. Kakamega bean 8 seeds were procured from Kenya Seed Co Ltd where the price was same for both seasons. Labour cost consisted of land and tied ridges preparation, TSP and CAN fertilizer application, planting, 1^{st} and 2^{nd} weeding, cost of spraying as well harvesting and threshing. The total yield of dry bean per hectare was determined by kg/ha while total cost of production (Ksh./ha) was determined by adding all cost of inputs (cost of fertilizer, pesticide/fungicide, seeds) and labour.

Income (Ksh./ha) = Yield of dry beans in kg*price/kg. The bean price at the time was Ksh. 60.00/kg during first and second planting. Net profit was obtained from income minus total cost of production.

4.3.6 Data analysis

All data collected were subjected to analysis of variance (ANOVA) to evaluate the treatment effects using Genstat 15th Edition statistical software (Lane and Payne, 2006). Mean separation was done using the least significant difference value at the $p<0.05$ probability level

4.4 Results

4.4.1 Effect of tied ridges and plant density on pod length, seed per pod and pods per plant of dry bean during short rains of 2012

During the short rains of 2012, the interaction between tied ridges and plant density had no significant effect observed on pod length, number of seeds per pod and number of pods per plant. Pods length ranges from 7.1 cm to the highest 8.5 cm from all treatments while number of seeds per pod ranges from 3 to 4. Number of pods per plant ranges from 4.3 observed under tied ridges with the highest density of 185185 plants/ha to 7.7 observed in 111111 plants/ha which was highest (Table 4.1).

Table 4.1: Means of pods length, pods/ plant and seeds/pod of dry bean due to the effect of tied ridges and plant density during 2012 short rain

	Pod length			Seeds/pod			Pods/plant		
Plants/ha	CT	TR	Means	CT	TR	Means	CT	TR	Means
185,185	7.2	8.3	7.7	3.6	3.6	3.6	6.1	4.3	5.2
148,148	7.1	8.5	7.8	3.1	4	3.5	6.6	5.6	6.1
111,111	7.7	8.2	7.9	3.3	3.7	3.5	7.7	6	6.8
	7.3	8.3		3.2	3.8		6.8	5.3	
$LSD_{P<0.05}$	T=NS			T=NS			T=NS		
$LSD_{P<0.05}$	D=NS			D=NS			D=NS		
$LSD_{P<0.05}$	T*D=NS			T*D=NS			T*D=NS		

	CV%=7.6	CV%=11	CV%=9.3

LSD $_{p<0.05}$; Least significant difference at 5% level; CT=Conventional tillage; TR= Tied ridges; D=Density; NS= Not significant

4.4.2 Effect of tied ridges and plant density on grain yield and 1000 seed weight of dry bean during short rains of 2012

The yield of dry bean and 1000-grain weight was also not significantly improved by tied ridges and plant density during short rains season in all treatments (Table 4.2). Yield of 2667 kg/ha was observed under conventional tillage in population of 111111 plants/ha, 2639 kg/ha and 2583 kg/ha in population of 148,148 and 185185 respectively. Generally, this was higher than yield observed under tied ridges in all densities from 2000 kg/ha in 185,185 plants/ha to highest 2306 kg/ha in 111111 plants/ha population. Treatment observed with the heaviest 1000-grain weight was under conventional tillage with lowest density of 111111 plants/ha.

Table 4.2: Means of 1000 seeds weight and grain yield of dry bean due to the effect of tied ridges and plant density during short rain season (SR 2012)

	1000 seeds weight(g)			Grain yield (kg ha^{-1})		
Plants/ha	CT	TR	Means	CT	TR	Means
185,185	400	398	399	2667	2306	2486.5
148,148	405	400	402	2639	2194	2416.5
111,111	410	400	405	2583	2000	2291.5
	403	399		2629	2166	
LSD$_{P<0.05}$	T=NS			T=NS		
LSD$_{P<0.05}$	D=NS			D=NS		
LSD$_{P<0.05}$	T*D=NS			T*D=NS		
	CV%=4.7			CV%=10.1		

LSD $_{p<0.05}$; Least significant difference at 5% level; CT=Conventional tillage; TR= Tied ridges; D=Density; NS= Not significant

4.4.3 Effect of tied ridges and plant density on pod length, seed per pod and pods per plant of dry bean during long rains of 2013

During the long rain season of 2013, no significant effect observed due to tied ridges and their interaction with plant density on parameters observed including pods length, seeds per pod and number of pods per plant (Table 4.3). The number of seeds per pod ranged from 3 to 4 in all treatments while there was no much difference observed in the size of the pods where most were statistically similar (10 cm). However, plant density had a significant effect on number of pods per plant with more pods being observed under tied ridges with lowest density of 111111 plants/ha.

Table 4.3: Means of pods length, pods/ plant and seeds/pod of dry bean due to the effect of tied ridges and plant density during 2013 long rains Pod.

	Length			Seeds/pod			Pods/plant		
Plant/ha	CT	TR	Means	CT	TR	Means	CT	TR	Means
185,185	9.3	10	9.6	3.7	3.1	3.2	6.6	9.2	7.9
148,148	10	10	10	3	3.8	3.4	9	10.3	9.6
111,111	10	10	10	3.8	3.9	3.9	10	11.3	10.7
	9.9	10		3.5	3.6	3.5	8.5	10.3	
$LSD_{P<0.05}$	T=NS			T=NS			T=NS		
$LSD_{P<0.05}$	D=NS			D=NS			D=2.7		
$LSD_{P<0.05}$	T*D=NS			T*D=NS			T*D=NS		
	CV%=5			CV%=6.5			CV%=21.5		

$LSD_{p<0.05}$; Least significant difference at 5% level; CT=Conventional tillage; TR= Tied ridges; D=Density; NS= Not significant

4.4.4 Effect of tied ridges and plant density on grain yield and 1000 seed weight of dry bean during long rains of 2013

During second planting of long rains 2013, there was significant (P<0.05) interaction between tied ridging and plant density on grain yield of dry bean (Table 4.4). Beans planted under tied ridges with higher population of 185185 plants ha^{-1} recorded the highest yield of 4184 kg/ha. This was significantly higher than 3111 kg/ha observed at 148,148 plants ha^{-1} and 2598 kg/ha observed at 11111 plants/ha under tied ridges. Under conventional tillage, there were no significant differences observed on grain yield in all plant densities. Grain yield ranges from 2303kg/ha in lower density of 111111 plants/ha to 2664 kg/ha in the highest density of 185185 plants/ha. There was no significant difference observed in the weights of 1000 seeds in all treatments although the heaviest grains were observed with decreased plant density of 111111 plants/ha

Table 4.4: Means of 1000 seeds weight and grain yield of dry bean due to the effect of tied ridges and plant density during short rain season (LR2013)

	1000 seeds weight			Grain yield, kg ha^{-1}		
Plants/ha	CT	TR	Means	CT	TR	Means
185,185	400	420	410	2664	4184	3424
148,148	410	430	420	2609	3111	2860
111,111	410	440	425	2303	2598	2450
	406	430		2526	3297	
$LSD_{P<0.05}$	T=NS			T=NS		
$LSD_{P<0.05}$	D=NS			D=436.1		
$LSD_{P<0.05}$	T*D=NS			T*D=1242		
	CV%=5.4			CV%=11.2		

$LSD_{p<0.05}$; Least significant difference at 5% level; CT=Conventional tillage, TR=Tied ridges; D= Density; NS= Not significant

Treatments cost Table 4.5: Production costs (Ksh./ha) of dry bean per season (1st and 2nd planting 2012/2013)

Fertilizer (TSP)	3200
Fertilizer (CAN)	1600
Pestcide: Bestox	4600
Fungicide: Antracol	2600
Seeds: Kakamega bean 8	5000
Land preparation	10000
Ridging	8000
Planting	8000
1st and 2nd Weeding	12000
Spraying	3000
Harvesting and threshing	10000
Total costs of production	**68000**

During short rains of 2012, profit ranges from Ksh.54000/ha (tied ridges + 111111 plants/ha) which was lowest to the highest profit of Ksh. 97020/ha (conventional tillage + 185185 plants/ha) (Table 4.6). Dry bean planted under conventional tillage provided the highest average net profit relative to the one planted under tied ridges in all plant densities during this season. During the long rains season, the average net profit obtained was higher under tied ridges than conventional tillage. Under tied ridges profit ranges from Ksh. 183040/ha in 185185 plants/ha to Ksh. 89880/ha obtained in lower density of 111111 plants/ha.

Table 4. 6: Effect of tillage practices and plant density on average profit/ha (Ksh.) of dry bean (Short rain 2012)

Tillage practice	**Density (plants/ha)**	**Grain yield (kg/ha)**	**Income (Ksh./ha)**	**Cost (Ksh./ha)**	**Profit (Ksh./ha)**
Conventional tillage	185,185	2667	160020	63000	97020
Conventional tillage	148,148	2639	158340	62000	96980
Conventional tillage	111,111	2583	154980	61000	93980
Tied ridges	185,185	2306	138360	68000	70360
Tied ridges	148,148	2194	131640	67000	64640
Tied ridges	111,111	2000	120000	66000	54000

Table 4.7: Effect of tillage practices and plant density on average profit/ha (Ksh.) of dry bean (Long rain 2013)

Tillage practice	**Density (Plants/ha)**	**Grain yield (kg/ha)**	**Income (Ksh./ha)**	**Cost (Ksh./ha)**	**Profit (Ksh./ha)**
Conventional tillage	185,185	2664	159840	63000	96840
Conventional tillage	148,148	2609	156540	62000	94540
Conventional tillage	111,111	2303	138180	61000	77180
Tied ridges	185,185	4184	251040	68000	183040
Tied ridges	148,148	3111	186660	67000	119660
Tied ridges	111,111	2598	155880	66000	89880

Tied ridges provided the highest cumulative net profit where higher density of 185185 plants/ha was used during long rain season while plots under tied ridges with the lowest population had the least cumulative net profit (Table 4.8). Under conventional tillage, plots with higher density had the highest cumulative net profit

Table 4.8: Cumulative net profit (Ksh./ha) of dry bean for two seasons short and long rains 2012/2013

Tillage practice	Plant density (plants/ha)	First planting net profit(Ksh./ha) (short rains 2012)	Second planting net profit(Ksh./ha) (long rains 2013)	Cumulative net profit (Ksh./ha)
Conventional tillage	185185	97020	96840	193860
Conventional tillage	148148	96980	94540	191520
Conventional tillage	111111	93980	77180	171160
Tied ridges	185185	70360	183040	253400
Tied ridges	148148	64640	119660	184300
Tied ridges	111111	54000	89880	143880

4.5 Discussion

To improve on crop production, it is important to note that soil and water conservation methods should be integrated with other agronomic practices so that water retained could be used effectively. Such practices may include use of tied ridges for water harvesting, use of fertilizers and use of improved crop management like use of appropriate plant density. One of the most important factors to gain highest yields in dry bean is determining appropriate plant density according to the climatic conditions and aspect of moisture (Saed *et al.,* 2010). The total density for beans that can be sustained depends on environmental resources available, particularly soil and water, nutrients and appropriate density to improve water use efficiency (Koli and Akasha, 1995). Grain yield in dry bean is a product of several yields components and they are generally the products of sequential developmental processes. The number of pods per plant, seeds per plant, seeds per pod and 1000-seed weight are yield contributing characters that determine productive potential of common bean and it changes in response to plant density (Zaimoglu *et al.*, 2004).

The results showed that use of tied ridges, plant density and their interaction had no significant effect on yield and yield components ($P \leq 0.05$) of dry bean during short rain season of 2012. Yield of dry bean obtained under tied ridges in the three different plant densities was lower than under conventional tillage with highest recorded at higher plant density of 185185 plants/ha. During this season low rainfall was observed and the rainfall ceased when the crop was at flowering stage. As a result, flowers may have aborted and this led to poor pod setting hence the reduction in yield especially under tied ridges plots. Also exposure of soil surface to extreme weather through construction of tied ridges when the rainfall was low could have led to high evaporation resulting to less or no moisture conserved hence less yield realized under tied ridges compared to conventional tillage. Similar results were reported by Gursoy *et al,* (2011) who confirmed that tied ridges enhanced drying of the seed zones thus the low moisture content observed.

However, plant density was found to have an influence on yield and yield components of dry beans. From the results obtained, yield components including number of pods per plant, size of the pod, seeds per pod and 1000-grain weight were found to decrease with increase of plant density. The highest grain yield was attained at higher plant density under both tillage practices. The lowest plant densities produced the higher number of pods per plant as compared to higher density in both tillage practices. This could have been as a result of low competition for resources between plants hence there was more light interception which consequently may have resulted in increased photosynthetic efficiency thus increasing number and quality of the bean pods. Similar findings have been reported by Bakry *et al*, (2011) and Khalil *et al*, (2010) that, increased number of pods under low plant densities could be attributed to greater light capture coupled with less interplant competition and this allows efficient utilization and partitioning of photosynthates into seed production. These findings are in agreement with Ayaz *et al*., (2001) who reported that as plant density increase, intensity of interplant competition increases and reduce many parameters (number of pods/plant, seed per pod, 1000 seed weight and seed yield/plant) in the individual plants although seeds yield per unit area, total dry matter and harvest index increased as the plant population increased. Similarly, Al-Abduselam and Abdal (1995) reported that the reduction in pods per plant, number of seed per pod, 1000 seed weight and yield per plant in higher densities could be attributed to changes in canopy structure due to changes in density and hence in the light interception by the crop.

A 1000-seed weight decreased with increase of plant density. Low plant density could have lowered competition for growth resources between crops hence more leaves produced. This might have resulted to more leaves surface area which could have led to more transfer of photosynthetic materials to the grain hence higher grain filling due to larger accumulation of assimilates. The same results were reported by Al-Rifael *et al*, (2004) found that lower plant population produced seeds with heavier 1000 grain weight seeds. He stated that less competition between plants under lower populations might increase the available assimilates per pod and result in increased seed weights. Low plant populations offer sufficient resources availability and ensure maximum conversion of these resources into assimilates which are stored in seeds resulting into increased seed weight.

In the second season of long rains 2013, incorporating tied ridges with plant density significantly improved the yield of dry bean. Bean planted under tied ridges with the highest plant density of 185185 plants/ha produced the highest yield as compared to conventional tillage with the same density. In this season, the amount of rainfall received was slightly higher than the first season leading to water being harvested and retained by tied ridges. As a result, tied ridges could have conserved sufficient soil moisture required for development and production especially at the critical stage of growth such as flowering and seed formation hence improving yield. These outcomes are in agreement with Mupangwa and Twomlow (2006) and Nyamadzawo *et a*l, (2013) who revealed that tied ridges are effective at trapping and concentrating moisture in the root zone of plants. Also plant density significantly ($P \leq 0.05$) influenced grain yield of dry bean where higher yield was attained under higher plant densities. In other words, decrease in yield of each plant at high densities compensates for more number of plants per unit area (Saeid *et al*., 2010).

CHAPTER FIVE: GENERAL DISCUSSION, CONCLUSION AND RECOMMENDATIONS

5.1 General discussion

In the first planting of short rains 2012, yield of maize decreased in plots under tied ridges in all three fertilizers levels applied. The lowest grain yield was recorded in plots with zero fertilizer while highest was at 20N+40P application. Yield of maize and sorghum increased in plots under conventional tillage as compared to tied ridges plot with the highest values registered where 20 kg N ha^{-1}+40 kg P $ha^{-1}$was applied. Also small values of ears and panicles, number of grains per ear/panicle and the 1000 grain weight was registered in tied ridges plots relative to conventional tillage at all three levels of fertilizer studied with the lowest recorded in plots where no fertilizer was applied. Similarly, in the same season of short rains, grain yield of dry bean decreased under tied ridges plots as the plant density decreased. Higher yield was registered in plots under conventional tillage with the highest recorded in treatment with high plant density of 185185 plants/ha. The number of pods per plant, seeds per pod and the length of pods decreased as the plant density increased and this was equally noticed in both tillage practices.

The low yields observed on maize, sorghum and dry beans and small values of yield related parameters observed in all the treatments under tied ridges during short rains of 2012 could be associated with low rainfall received during this season and again there was a period of dry spell where there was no rain when the crops were flowering. As a result, there was no water to be harvested by tied ridges leading to limited or no moisture to conserve and this could have resulted to low the yields observed. Also as the tied ridges were prepared, this could have also exposed soil to harsh condition of evaporation hence the soil dried faster as compared to conventional tillage where the soil was less disturbed and this could be explained by higher yield registered in maize, sorghum and dry bean under conventional tillage system.

During the second season of the long rains, yield of maize significantly increased in plots under tied ridges and NP fertilizer. The yield of maize increased when NP fertilizer was applied at 20 kg N ha^{-1} + 40 kg P ha^{-1}under tied ridges but decreased when no fertilizer was applied. Yield observed under conventional tillage was generally lower in all NP fertilizer levels as compared to one registered under tied ridges. Higher yield registered in plots under tied ridges could be probably explained due to the adequate rainfall received during this season especially in the month of April-May 2013. As a result, tied ridges could have trapped and retained more water and this might have improved the soil moisture leading to a higher yield. Availability of soil moisture could have enhanced nutrients uptake and nutrient availability supplied by NP fertilizers affecting the yields. Tied ridges also gave more time for the rain water to penetrate and infiltrate hence enabling the crops to utilize the nutrients efficiently which in turn translated to a higher yield. These outcomes are also in agreement with Nyamadzawa *et al* (2013) who revealed that tied ridges are effective at trapping and concentrating moisture in the root zone leading to higher grain. This study also revealed that NP fertilizer had effect on maize grain yield and this result agreed with the report of Abdulahi *et al.* (2005) who reported that the addition of nitrogen fertilizer results large increase in yield for cereal crops.

Significant difference was also found on 1000 grain weight of maize due to interaction effect between tied ridging and NP fertilizer with the heaviest grains registered at 20N+40P application over conventional tillage at all three fertilizer levels studied. This heavier seeds could be as a result of larger volume of seeds due to larger accumulation of assimilates. Alemayehu (1995) also suggested that the main reason for increased seed weight could be due to addition of supply of assimilates both at anthesis and grain filling.

Application of 40 kg N ha^{-1} +40 kg P ha^{-1}in tied ridges plots increased stovers yield whereas low yield was recorded in plots where fertilizer was not applied. This was significantly higher as compared to yield registered under conventional tillage with the same application. This is an indication that nitrogen results into high biomass production and that tied ridging contributed greatly to increased moisture availability through water conservation thereby enabling efficient utilization of N. Nitrogen was readily absorbed and taken up by plant and this could have led to increased vegetative growth. Nitrogen plays a key role in vegetative growth because it is involved in protein synthesis which promotes plant growth (Hassan *et al* 2010). Similar findings were reported by Okpara (2000) who suggested that application of nitrogen fertilizer to crops facilitates development of leaf area and lateral stem as a result of increased physiological indices.

For dry bean, tie-ridging and plant density of 185,185 plants/ha significantly improved the yield while the least value of yield was registered in low plant densities (111,111 plants/ha). Significant difference was also found due to plant density for the yield of dry bean where highest grain yield was recorded at higher plant density of 185185 plants/ha. Generally, the yield of bean decreased as the plant density decrease. The number of pods per plant increased as plant density decreased in both tillage practices while pods length recorded was higher and almost similar under tied ridges in lower density. Seeds per pod registered under tied ridges were statistically similar but higher in low plant density. Similar findings have been reported by Ayaz *et al*, (2001) who found that as plant density increase (narrow spacing) intensity of interplant competition increases and reduce many parameters (number of pods/plant, pod length, 1000 seed weight and seed yield/plant) in the individual plants of faba beans although seed yield per unit area, total dry matter and harvest index increased as plant population increased. There was no significant difference observed on 1000 seed weight due to tied ridges and plant density. This result agrees with previous papers which found out that 1000-seed weight was not significantly affected by plant densities (O'Donovan, 1996). Maobe *et al* (2014) also reported non-significant effect of 1000 grain weight due to increased or decreased plant density.

5.2 Conclusion

The results from the study have demonstrated that the magnitude of yield response to tied ridging, NP fertilizer and plant density varies with crop, cropping system, region and rainfall regime. From the findings of the study, the combination of tie-ridging and NP fertilizers resulted in increased yield and yield components of maize and vegetative growth of sorghum during long rains when the rainfall was high. Also combination of tied ridges and plant density of 185185 plants/ha resulted in increased yield of dry bean when the rainfall was slightly higher. Therefore, in order to promote yield of maize, dry bean and vegetative growth of sorghum there is need incorporate NP fertilizer and appropriate plant density in addition to soil moisture conservation.

In Kabete region which represents wet/ warmer environments, for dry bean production as a sole crop, it would be unnecessary to institute tied ridges with any plant populations studied for dry bean production under drier condition. But tie ridging will only improve the yield when combined with plant density at the recommended spacing which was found to be optimal at inter row spacing of 45 cm x 12 cm (185,185 plants/ha).

For maize and sorghum production it was found that tied ridges depended on crop and rainfall regimes and incorporating the tillage with fertilizer had an added advantage. Use of tied ridges alone with adequate rainfall did not improve the yield of both crops but when incorporated with N fertilizer at the level of 20 kg N ha^{-1}, yield was significant.

From the findings of the study, it may be therefore concluded that incorporating tied ridges as water conservation technology with NP fertilizer input application and using appropriate density can be the key aspects to be considered by the farmers from central region in order to improve maize and dry bean yield as well as promoting vegetative growth of sorghum when the rainfall is high. The effectiveness of tied ridges and NP fertilizer in increasing maize yield was observed with 20N+40P fertilizer levels per hectare while tied ridges proved to be more effective in conserving water and increasing the yield of dry bean with population of 185,185 plants/ha with relatively consistent effects during long rains season than conventional tillage.

However, due to non-significance and inconsistent data observed in the two seasons for sorghum, this study concludes that a long term experiment is required to be carried on to find whether tied ridges as water harvesting technology is necessary for sorghum production in central region.

Economically, use of tied ridges and NP fertilizer at the rate of 20 kg N ha^{-1} +40 kg P ha^{-1} was found economical in maize production which registered the highest net profit while use of tied ridges and population of 185185 plants/ha on dry bean production registered the highest net profit.

5.3 Recommendations

1. A similar study involving other crops like vegetables, potatoes or other field crops should be conducted in this region using the same technology to find whether their production could be improved.

2. The study could be repeated in a long term period to ascertain the lasting impact of tied ridges in Central Kenya.

3. A study on tissue analysis in the laboratory could be done to evaluate the effect of use of tied ridges and N and P fertilizer on nutritional qualities of maize and sorghum products.

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APPENDICES

Appendix 1a: Analysis of variance (ANOVA) table for effect of tied ridges and NP fertilizer on grain yield of maize (SRS 2012)

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
REP	2	543735.	271867.	0.18	
Tillage	1	4132812.	4132812.	2.78	0.238
Residual	2	2978342.	1489171.	1.73	
Fertilizer	2	2349434.	1174717.	1.36	0.310
Tillage.Fertilizer	2	1836846.	918423.	1.06	0.389
Residual	8	6899753.	862469.		
Total	17	18740923.			

Appendix 1b: Analysis of variance (ANOVA) table for effect of tied ridges and NP fertilizer on the grain yield of maize (LRS 2013)

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
REP stratum	2	1116161.	558080.	5.98	
Tillage	1	1147612.	1147612.	12.29	0.073
Residual	2	186739.	93369.	0.25	
Fertilizer_	2	12015979.	6007990.	15.78	0.002
Tillage.Fertilizer	2	2517081.	1258541.	3.31	0.090
Residual	8	3046136.	380767.		
Total	17	20029708.			

Appendix 2a: Analysis of variance (ANOVA) table for effect of tied ridges and fertilizer on stover yield of maize (SRS 2012)

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
REP stratum	2	87.54	43.77	547.11	
REP.Tillage stratum					
Tillage	1	49.01	49.01	612.56	0.002
Residual	2	0.16	0.08	0.0	
Fertilizer	2	22.69	11.34	0.66	0.545
Tillage.fertilizer	2	58.51	29.25	1.69	0.244
Residual	8	138.53	17.32		
Total	17	356.43			

Appendix 2b: Analysis of variance (ANOVA) table for effect of tied ridges and fertilizer on stover yield of maize (LRs 2013)

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
REP stratum	2	33.888	16.944	1.78	
Tillage	1	0.405	0.405	0.04	0.856
Residual	2	19.023	9.512	2.54	
Fertilizer	2	261.688	130.844	34.94	<.001
Tillage.Fertilizer	2	19.110	9.555	2.55	0.139
Residual	8	29.956	3.744		
Total	17	364.069			

Appendix 3a: Analysis of variance (ANOVA) table for effect of tied ridges and fertilizer on the weight of 1000 grains of maize (SRs 2012)

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
REP stratum	2	4433.	2217.	2.87	
Tillage	1	672.	672.	0.87	0.449
Residual	2	1544.	772.	0.73	
Fertilizer	2	2100.	1050.	0.99	0.413
Tillage.fertilizer	2	1811.	906.	0.85	0.461
Residual	8	8489.	1061.		
Total	17	19050.			

Appendix 3b: Analysis of variance (ANOVA) table for effect of tied ridges and fertilizer on the weight of 1000 grains of maize (LRs 2013)

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
REP stratum	2	3744.4	1872.2	6.88	
Tillage	1	555.6	555.6	2.04	0.289
Residual	2	544.4	272.2	0.28	
Fertilizer	2	577.8	288.9	0.30	0.747
Tillage.Fertilizer	2	11911.1	5955.6	6.23	0.023
Residual	8	7644.4	955.6		
Total	17	24977.8			

Appendix 4a: Analysis of variance (ANOVA) table for effect of tied ridges and fertilizer on the length of the ears of maize (SRs 2012)

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
REP stratum	2	71.684	35.842	2.37	
Tillage	1	0.142	0.142	0.01	0.932
Residual	2	30.271	15.136	2.37	
Fertilizer	2	16.741	8.371	1.31	0.321
Tillage.Fertilizer	2	5.914	2.957	0.46	0.645
Residual	8	51.004	6.376		
Total	17	175.758			

Appendix 4b: Analysis of variance (ANOVA) table for effect of tied ridges and fertilizer on the sizes of the ears of maize (LRs 2013

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
REP stratum	2	30.25	15.13	10.69	
Tillage	1	0.80	0.80	0.57	0.530
Residual	2	2.83	1.42	0.07	
Fertilizer	2	9.00	4.50	0.21	0.812
Tillage.fertilizer	2	30.14	15.07	0.72	0.517
Residual	8	168.28	21.03		
Total	17	241.30			

Appendix 5a: Analysis of variance (ANOVA) table for effect of tied ridges and fertilizer on the number of grains per ear (SRs 2012)

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
REP stratum	2	13699.	6850.	0.97	
Tillage	1	501.	501.	0.07	0.815
Residual	2	14099.	7050.	2.91	
Fertilizer	2	7415.	3708.	1.53	0.274
Tillage.Fertilizer	2	1052.	526.	0.22	0.809
Residual	8	19372.	2422.		
Total	17	56140.			

Appendix 5b: Analysis of variance (ANOVA) table for effect of tied ridges and fertilizer on the number of seeds per ear of maize (LRs 2013)

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
REP stratum	2	4303.	2152.	221.30	
Tillage	1	1136.	1136.	116.85	0.008
Residual	2	19.	10.	0.01	
Fertilizer	2	997.	498.	0.40	0.683
Tillage.fertilizer	2	2615.	1308.	1.05	0.393
Residual	8	9960.	1245.		
Total	17	19030.			

Appendix 6a: Analysis of variance (ANOVA) table for effect of tied ridges and NP on fertilizer on grain yield of sorghum (SRS 2012)

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
REP stratum	2	524651.	262325.	0.06	
Tillage	1	5340396.	5340396.	1.31	0.370
Residual	2	8134119.	4067060.	0.33	
Fertilizer	2	43707768.	21853884.	1.75	0.234
Tillage.fertilizer	2	269309.	134655.	0.01	0.989
Residual	8	99996480.	12499560.		
Total	17	157972723.			

Appendix 6b: Analysis of variance (ANOVA) table for effect of tied ridges and NP on fertilizer on grain yield of sorghum (LRS 2013)

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
REP stratum	2	3143910.	1571955.	0.11	
Tillage	1	110973.	110973.	0.01	0.937
Residual	2	28082015.	14041007.	1.53	
Fertilizer	2	17222751.	8611376.	0.94	0.430
Tillage.Fertilizer	2	6881686.	3440843.	0.37	0.699
Residual	8	73424083.	9178010.		
Total	17	128865418.			

Appendix 7a: Analysis of variance (ANOVA) table for effect of tied ridges and fertilizer on the weight of 1000 grains of sorghum (SRS 2012)

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
REP stratum	2	233.33	116.67	1.00	
Tillage	1	0.00	0.00	0.00	1.000
Residual	2	233.33	116.67	2.00	
Fertilizer	2	33.33	16.67	0.29	0.759
Tillage.fertilizer	2	33.33	16.67	0.29	0.759
Residual	8	466.67	58.33		
Total	17	1000.00			

Appendix 7b: Analysis of variance (ANOVA) table for effect of tied ridges and fertilizer on the weight of 1000 grains of sorghum (LRS 2013)

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
REP stratum	2	233.33	116.67	0.78	
Tillage	1	50.00	50.00	0.33	0.622
Residual	2	300.00	150.00	3.60	
Fertilizer	2	33.33	16.67	0.40	0.683
Tillage.Fertilizer	2	100.00	50.00	1.20	0.350
Residual	8	333.33	41.67		
Total	17	1050.00			

Appendix 8a: Analysis of variance (ANOVA) table for effect of tied ridges and NP on fertilizer on panicle length of sorghum (SRS 2012)

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
REP stratum	2	8.72	4.36	0.53	
Tillage	1	23.58	23.58	2.87	0.232
Residual	2	16.43	8.22	0.60	
Fertilizer	2	2.83	1.42	0.10	0.903
Tillage.fertilizer	2	4.43	2.22	0.16	0.854
Residual	8	109.70	13.71		
Total	17	165.69			

Appendix 8b: Analysis of variance (ANOVA) table for effect of tied ridges and NP on fertilizer on panicle length of sorghum (LRS 2013)

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
REP stratum	2	1.721	0.861	0.72	
Tillage	1	7.867	7.867	6.59	0.124
Residual	2	2.388	1.194	0.54	
Fertilizer	2	231.764	115.882	52.01	<.001
Tillage.Fertilizer	2	31.444	15.722	7.06	0.017
Residual	8	17.824	2.228		
Total	17	293.009			

Appendix 9a: Analysis of variance (ANOVA) table for effect of tied ridges and NP on fertilizer on number of grains per panicle (SRs 2012)

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
REP stratum	2	19552.	9776.	0.05	
Tillage	1	178603.	178603.	0.96	0.431
Residual	2	373945.	186972.	4.26	
Fertilizer	2	184542.	92271.	2.10	0.185
Tillage.fertilizer	2	67375.	33688.	0.77	0.496
Residual	8	351271.	43909.		
Total	17	1175288.			

Appendix 9b: Analysis of variance (ANOVA) table for effect of tied ridges and NP on fertilizer on number of grains per panicle (LRS 2013)

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
REP stratum	2	2580.	1290.	0.19	
Tillage	1	7771.	7771.	1.17	0.392
Residual	2	13277.	6638.	0.92	
Fertilizer	2	177456.	88728.	12.35	0.004
Tillage.Fertilizer	2	11888.	5944.	0.83	0.471
Residual	8	57454.	7182.		
Total	17	270426.			

Appendix 10a: Analysis of variance (ANOVA) table for effect of tied ridges and NP on fertilizer on stover yield of sorghum (SRS 2012)

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
REP stratum	2	14.08	7.04	0.14	
Tillage	1	0.01	0.01	0.00	0.988
Residual	2	101.69	50.85	4.51	
Fertilizer	2	16.33	8.17	0.72	0.514
Tillage.fertilizer	2	29.78	14.89	1.32	0.320
Residual	8	90.22	11.28		
Total	17	252.13			

Appendix 10b: Analysis of variance (ANOVA) table for effect of tied ridges and NP on fertilizer on stover yields of sorghum (LRS 2013)

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
REP stratum	2	13.381	6.691	0.53	
Tillage	1	4.909	4.909	0.39	0.598
Residual	2	25.454	12.727	4.32	
Fertilizer	2	175.441	87.721	29.76	<.001
Tillage.Fertilizer	2	19.981	9.991	3.39	0.086
Residual	8	23.584	2.948		
Total	17	262.751			

Appendix 11a: Analysis of variance (ANOVA) table for effect of tied ridges and plant density on grain yields of dry bean (SRS 2012)

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
REP stratum	2	1320793.	660397.	1.97	
Tillage	1	1993339.	1993339.	5.94	0.135
Residual	2	671201.	335600.	1.39	
Densities	2	780363.	390182.	1.62	0.257
Tillage.Densities	2	898939.	449470.	1.86	0.216
Residual	8	1928744.	241093.		
Total	17	7593380.			

Appendix 11b: Analysis of variance (ANOVA) table for effect of tied ridges and plant population density on grain yields of dry bean (LRS 2013)

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep stratum	2	790394.	395197.	0.66	
Tillage	1	2680384.	2680384.	4.45	0.169
Residual	2	1204635.	602318.	5.61	
Density	2	2858688.	1429344.	13.32	0.003
Tillage.Density	2	1292288.	646144.	6.02	0.025
Residual	8	858162.	107270.		
Total	17	9684552.			

Appendix 12a: Analysis of variance (ANOVA) table for effect of tied ridges and plant population density on the number of pods per plant of dry bean (SRS 2012)

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
REP stratum	2	12.444	6.222	0.44	
Tillage	1	4.500	4.500	0.32	0.628
Residual	2	28.000	14.000	3.27	
Densities	2	29.778	14.889	3.48	0.082
Tillage.Densities	2	5.333	2.667	0.62	0.560
Residual	8	34.222	4.278		
Total	17	114.278			

Appendix 12b: Analysis of variance (ANOVA) table for effect of tied ridges and plant population density on the number of pods per plant of dry bean (LRS 2013)

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep stratum	2	43.000	21.500	6.79	
Tillage	1	18.000	18.000	5.68	0.140
Residual	2	6.333	3.167	1.41	
Density	2	2.333	1.167	0.52	0.614
Tillage.Density	2	4.333	2.167	0.96	0.422
Residual	8	18.000	2.250		
Total	17	92.000			

Appendix 13a: Analysis of variance (ANOVA) table for effect of tied ridges and plant population density on the size of the pods of dry bean (SRS 2012)

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
REP stratum	2	0.7678	0.3839	0.71	
Tillage	1	0.0022	0.0022	0.00	0.955
Residual	2	1.0744	0.5372	2.14	
Densities	2	1.4878	0.7439	2.97	0.109
Tillage.Densities	2	0.9811	0.4906	1.96	0.203
Residual	8	2.0044	0.2506		
Total	17	6.3178			

Appendix 13b: Analysis of variance (ANOVA) table for effect of tied ridges and plant population density on the size of the pods of dry bean (LRS 2013)

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep stratum	2	2.3700	1.1850	4.17	
Tillage	1	1.7422	1.7422	6.14	0.132
Residual	2	0.5678	0.2839	0.77	
Density	2	0.8933	0.4467	1.21	0.347
Tillage.Density	2	0.4578	0.2289	0.62	0.561
Residual	8	2.9489	0.3686		
Total	17	8.9800			

Appendix 14a: Analysis of variance (ANOVA) table for effect of tied ridges and plant population density on the weight of 1000 seeds of dry bean (SRS 2012)

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
REP stratum	2	28.781	14.391	2.02	
Tillage	1	28.627	28.627	4.02	0.183
Residual	2	14.254	7.127	1.84	
Densities	2	3.074	1.537	0.40	0.685
Tillage.Densities	2	1.688	0.844	0.22	0.809
Residual	8	31.038	3.880		
Total	17	107.463			

Appendix 14b: Analysis of variance (ANOVA) table for effect of tied ridges and plant population density on the weight of 1000 seeds of dry bean (LRS 2013)

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep stratum	2	21.213	10.607	1.09	
Tillage	1	1.389	1.389	0.14	0.742
Residual	2	19.538	9.769	1.88	
Density	2	2.253	1.127	0.22	0.810
Tillage.Density	2	6.191	3.096	0.60	0.574
Residual	8	41.576	5.197		
Total	17	92.160			

Appendix 15a: Analysis of variance (ANOVA) table for effect of tied ridges and plant population density on plant height (SRS 2012)

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
REP stratum	2	42.434	21.217	1.09	
Tillage	1	6.722	6.722	0.34	0.617
Residual	2	39.014	19.507	2.34	
Densities	2	12.934	6.467	0.78	0.492
Tillage.Densities	2	13.914	6.957	0.83	0.469
Residual	8	66.738	8.342		
Total	17	181.758			

Appendix 15b: Analysis of variance (ANOVA) table for effect of tied ridges and plant population density on plant height (LRS 2013)

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep stratum	2	99.003	49.502	4.96	
Tillage	1	16.627	16.627	1.67	0.326
Residual	2	19.948	9.974	3.40	
Density	2	14.070	7.035	2.40	0.153
Tillage.Density	2	12.781	6.391	2.18	0.176
Residual	8	23.496	2.937		
Total	17	185.925			

Appendix 16a: Analysis of variance (ANOVA) table for effect of tied ridges and plant population density on dry matter (SRS 2012)

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
REP stratum	2	11.900	5.950	1.76	
Tillage	1	1.479	1.479	0.44	0.576
Residual	2	6.754	3.377	2.63	
Densities	2	1.013	0.506	0.39	0.686
Tillage.Densities	2	1.898	0.949	0.74	0.507
Residual	8	10.257	1.282		
Total	17	33.300			

Appendix 16b: Analysis of variance (ANOVA) table for effect of tied ridges and plant population density on dry weight matter (LRS 2013)

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep stratum	2	17.57	8.790.	4.36	
Tillage	1	7.44	7.442.	3.69	0.195
Residual	2	4.03.	2.018.	2.00	
Density	2	3.41	1.710.	1.70	0.243
Tillage.Density	2	1.09	0.546.	0.54	0.602
Residual	8	8.06	1.008.		
Total	17	41.63.			

Appendix 17: Calculation of cost of inputs of maize (First & second planting: SR 2012/2013)

Input	Quantity	Rate (Ksh)	Total cost (Ksh)
Fertilizers			
TSP	40 kg	80	3200
CAN 1st split	20 kg	80	1600
CAN 2nd split	20 kg	80	1600
Maize seeds			
DK 8031	10 kg	175	1750
Labour:			
Land preparation,	5 Acre	2000	10000
Ridging,	12 man days	400	5000
Planting,	10 man days	400	4000
1st and 2nd weeding,	38 man days	400	15000
Top dressing,	10 man days	400	4000
Data collection	25 man days	400	10000
Harvesting and threshing	25 man days	400	10000
			66150

Appendix 18: Calculation of cost of inputs of sorghum per season (First planting: SR 2012 and LR 2013)

Input	Quantity	Rate (Ksh)	Total cost (Ksh)
Fertilizers			
TSP	40 kg	80	3200
CAN 1st split	20 kg	80	1600
CAN 2nd split	20 kg	80	1600
Pesticide			
Bestox	8 Unit/50 ml	300	2400
Sorghum seeds			
KARI Mtama 1	10 kg	200	4000
Labour:			
Land preparation, Ridging, Planting, 1st and 2nd Weeding, Top dressing, Spraying Birds scaring Harvesting and threshing	5 Acre 12 man days 19 man days 45 man days 5 man days 6 man days 56 man days 30 man days	2000 400 400 400 400 400 400 400	10000 8000 7600 18000 2000 3600 22400 12000 **96400**

Appendix 19: Calculation of cost of inputs of dry bean per season for two seasons (First planting: SR 2012 and second planting LR 2013)

Input	**Quantity**	**Rate (Ksh)**	**Total cost (Ksh)**
Fertilizers:			
TSP	40 kg	80	3200
CAN	20 kg	80	1600
Pesticide:			
Bestox	15 Unit/50 ml	300	4500
Fungicide:			
Antracol	2 unit/500 ml	1300	2500
Dry bean seeds:			
Kakamega bean 8	20 kg	250	5000
Labour:			
Land preparation,	5 Acre	2000	10000
Ridging,	20 man days	400	8000
Planting,	20 man days	400	8000
1st and 2nd Weeding	30 man days	400	12000
Spraying	8 man day	400	3200
Harvesting and threshing	25 man days	400	10000
		TOTAL	**68000**