Effects of Tillage Practices on Water Use Efficiency and Performance of Common Beans (*Phaseolus Vulgaris* L.) in Machakos County, Kenya

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DECLARATION

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DEDICATION

I dedicate this thesis to my loving wife Mrs. Veronica P. Johnson, my sons Jethro and Moses and daughter Ruth. I am really grateful for the understanding and sacrifices that you made, allowing me to pursue this study to completion. You will always remain dear to me and may the Almighty God reign His Grace upon your lives forever. Your prayers, encouragement, support and inspiration motivated me to achieve this milestone, thank you!

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LIST ABBREVIATIONS

CT	Conventional tillage
CA	Conservation agriculture
CEC	Cation exchange capacity
DLSC	Dryland Seed Company
DTCBV	Drought tolerant common bean varieties
ET	Evapotranspiration
ETo	Reference Evapotranspiration
FAO	Food and Agriculture Organization
KALRO	Kenya Agriculture Livestock and Research Organization
LAC	Latin America Caribbean
LR	Long rains
MT	Minimum tillage
RAW	Relative available water
RCBD	Randomized complete block design
SR	Short rains
TAW	Total available water content
WUE	Water use efficiency
ZT	Zero tillage

GENERAL ABSTRACT

In Kenya, one of the major and cheap source of protein is bean (*Phaseolus vulgaris* L.). The crop is consumed in almost every household in rural and urban areas on a daily basis due to its cheapest nutritional source. Machakos County, where the survey was conducted during 2016 / 2017 short and long rains (SR and LR) cropping seasons, is a semi-arid region faced by water scarcity, crop failures and low bean production due to drought and fertility issues. Crops such as common beans, especially the drought tolerant varieties, would be crucial in improving food security and incomes among the small scale farmers in the region due to its short maturity and ability to produce with little moisture. However, little is known about their adoption by the small scale farmers. In addition, information on their (WUE) and the contribution of tillage practices to their (WUE) is not known. This research targets to provide information on the adoption of these drought tolerant common bean varieties, their effects on WUE and documenting the effects of tillage practices on WUE and yields of these varieties.

This prompted a survey in three villages in Machakos County namely; Kyamuluu, Mwania and Kaathi villages during the short and long rain seasons (SR and LR). This was to sustain farmers participation in the selection process of varieties they think are high yielding and efficient in water utilization for the research experiment which in turn could help breeders understand the farmers desired needs. Survey data was collected through a Focus group approach where a total of 38 farmers were interviewed from these three villages in Machakos County. The farmers selected GLPX92, KAT/B1, KATX56 and KATRAM as the four varieties that are high yielding with higher WUE and higher market demand. However, results showed that there was significant relationship found between education level of the household heads and their awareness of the drought tolerant bean varieties, which implies that increased adoption of the farmers depends on their level of education.

Experimental data was collected from field work in Katumani experimental site while meteorological weather data such as rainfall, air temperature, humidity, wind speed and solar radiation, were collected from the meteorological station at the Katumani Dryland Research Center. These were used to compute ET crop using Pennman Monteith formula while data for yields were collected at harvest during crop maturity stage which was used in deriving WUE by dividing the weights of yields over ET crop. Experimental area for this research was $0.1ha^{-1}$ and each plot size was 2 m× 8 m totaling 48 plots and 4 blocks measuring 30.5 m ×8 m per block. Soil samples from the experimental area was collected using soil auger at 30 cm depth in a zig zag fashions for the entire field and composite samples were collected per block and taken to the University of Nairobi Upper Kabete Chemistry and soil physical lab for analysis while moisture data was collected from neutron probe readings from the experimental site after every two weeks from the total of 48 plots with 48 accessed tube excluding the two calibration tubes that were used in calibrating the probe.

Moisture readings and soil samples from four depths namely 20 cm, 40 cm, 60 cm and 80 cm was analyzed at Kenya Agriculture and Livestock Research Organization (KALRO), Kangemi laboratory. There were 12 treatments per block comprising of three tillage practices namely conventional tillage (CT), minimum tillage (MT) and zero tillage (ZT) and four varieties namely GLPX92, KATB1, KATX56 and KATRAM arranged in a 3×4 split plot randomized complete block designed replicated four times. Tillage systems were the main plot factors and varieties the sub-plot factors. Additionally, soil samples were collected using auger around the calibration tube at various depths as was done in the experimental plots, placed in samples bags and taken to the KALRO lab in Kangemi for analysis to determine the volumetric water content from the gravitation content during the cropping seasons 2016/2017 at various crop growth stages.

Results from this study, showed that 55% of the farmers obtained certified seeds for production while 45% are still using uncertified seeds. A regression and correlation analysis showed that preference of KATX56, KAT/B1, GLPX92 and KATRAM bean varieties led to an increased adoption by most farmers due to seeds availability by Government, the Dryland Seed Company (DLSC), Agro-dealers and Research Institutions. Most importantly, the farmers attributed their adoption to KATX56, GLPX92, KAT/B1 and KATRAM based on yields, market demand and WUE. The outcomes from the experiment showed that tillage and varieties had no influence on yields and WUE. It was observed that interaction between tillage and seasons influenced yields and WUE. However, interaction of conservation agriculture (CA) and season, gave increased yield and WUE of common bean varieties in drought-prone County of Machakos.

CHAPTER ONE

GENERAL INTRODUCTION

1.1 Background of the study

Common bean (*Phaseolus vulgaris* L), widely known as dry bean, is grown all year round and belongs to the genus, *Phaseolus*, with large pointed compound trifoliate leaves (Katungi *et al*., 2009). Katungi *et al*. (2009), described the crop as a self-pollinated plant whereas cross- pollination is possible due to contact of stigma with pollen coated bee. Alemu, (2017) reported the seeds of the crop to be non-endospermic and differed in size and color which are 7-16 mm long. Despite these qualities, the crop show differences in growth habits. Most predominant bean grown in Africa is the bushy type (Buruchara, 2007).

According to Katungi *et al.*(2009a), the crop serves as pivotal source of food and energy in both rural and urban households in Kenya, providing proteins, carbohydrates and minerals such as iron. Broughton *et al.* (2003), argues that the crop is a smallholder crop grown in rotation or mixed cropping systems in combination with banana, sorghum, maize and other crops. It is a promising crop in fighting hunger and increasing incomes and food security in Kenya, especially in drought prone areas like Machakos County, due to its short maturation period, high nutritional content and commercial potential (Karanja *et al.*, 2008; Katungi *et al.*, 2010).

Cultivation of common bean in Kenya is done all over the country but specifically in five regions within the country namely, Eastern, Central, Rift valley, Nyanza and Western. The cultivation of common beans in Kenya has stagnated at below 0.7 t ha^{-1} which is below the over 1.2 t ha^{-1} recorded in Uganda between 2012 - 2014 (Sibiko, 2012). This is against the maximum yield of about 2 t ha^{-1} for the improved varieties (Karanja *et al.*, 2008; Sibiko, 2012). This could have been caused by many challenges such as fungal and bacterial diseases, nitrogen and phosphorus deficiencies, bean stem maggot and most importantly drought (Beebe *et al.*, 2012). The main obstacle to common bean cultivation in drought prone areas of Kenya is water deficiency (Katungi *et al.,* 2010 ; Mburu, 2015). Singh *et al.*(2013) measure WUE as increased yield or by saving water. Moreover, there are so many factors that affect WUE and a few are drought, fertility factors, characteristic of the plant and agricultural practices like tillage, cropping systems among others. Furthermore, in a rainfed ecosystem, there are various techniques to increase WUE. Water productivity (also referred as water use efficiency) targets to increase sufficient biomass and yield with relative available water. Conservation tillage significantly minimized environmental degradation and increase agricultural outputs (Bill, 1990).

Compared to conventional tillage practices, conservation tillage practices minimum tillage (MT) and no-till (NT) minimize soil disturbance (Davies and Finney, 2002). Conservation agriculture is the incorporation of residue management with continuous groundcover and different crop management practices. Tillage systems have different meaning among various fields study. Minimum tillage refers to a system that do not tolerate high soil disturbance. This system has a lot of environmental benefits (Settle & Garba, 2011). There are inconsistencies in effect of minimum tillage practices due to the differences in cropping systems, soil types and the climate (Holland, 2004).

Currently, Kenya has many bean varieties with majority being drought tolerant. The most adopted varieties include *Mwitemania, Nyayo, Ngoloso, Wairimu, Kitui, Rosecoco* and *Mwezimoja* (Katungi *et al.*, 2011). Among the drought tolerant varieties, *Katumani Bean 1 (KAT/B1), Katumani X69 (KAT X69), Katumani X56 (KAT X56)* and *Katumani Bean 9 (KATB9)* are common in the market (Karanja *et al*., 2008). Recently introduced drought resistant common bean varieties in the Kenyan market include; *Mex 12, DNB 11-10, DSS 11-04, Kenya early, DMC 11-13, DRK 11-12* and *DPC 11-05* among others (Gathu *et al.*, 2012).

Despite Kenya having so many common bean varieties that are drought tolerant, little is known about their preference and adoption by farmers especially those in the semi-arid areas (Gathu *et al.*, 2012; Karanja *et al.*, 2008). Katungi *et al.* (2011), argues that farmers' inclusion of the selection of the crop varieties, with high water use efficiency (WUE), will increase high chances of adoption. Increased adoption of varieties that are highly water efficient by smallholders' farmers in drought prone regions of Kenya can greatly boost the incomes and food security in these areas.

However, tillage, a soil management practice and cropping systems, influenced WUE of crops in semi-arid environments as well as plant population in temperate and humid environments and nutrient management practices and water availability (Hatfield *et al.,* 2001; Mburu, 2015). Conservation agriculture improve water use efficiency by 25-40% (Hatfield *et al.,* 2001). Little information on how conservation tillage influences the water use efficiency (WUE) of drought tolerant crops with short maturity period such as beans is limiting the understanding on the importance of such practices in improving the production of drought tolerant common bean varieties.

1.2 Statement of the Problem

Machakos County is a semi-arid region faced by water scarcity. Crops such as common beans, especially the drought tolerant varieties, would be crucial in improving food security and incomes among the small scale farmers in the region. Despite the availability drought tolerant varieties in Kenya, little is known about their adoption by the small scale farmers amidst low production of common beans. In addition, information on their WUE and the contribution of tillage practices on their water productivity is scanty (Beebe *et al.*, 2013). Lack of this information could be contributing to the low yields of common beans in Kenya.

In addition to moisture limitation, many of bean producing regions in sub-Saharan Africa are faced with inherent yield limiting factors such as low soil fertility. Soil fertility problems can be attributed to low available phosphorus (P) and nitrogen (N), and soil acidity, which is associated with aluminum (AL) and manganese (Mn) toxicity (Vanlauwe *et al*., 2015). Wortmann *et al.* (1998), reported P deficiency in 65 to 80% of soils and N in 60% in bean production areas of Eastern and Southern Africa, while 45 to 50% are acidic with a pH less than 5.2, containing high level of Al or Mn. However, this research targets to provide information on the adoption of drought-tolerant common bean varieties by farmers in Machakos County; document the effect of tillage practices and varieties on yield and WUE.

1.3 Justification

Common bean is cultivated by smallholder farmers especially women living in areas considered marginal in Kenya. They provide nutrition to households in terms of protein, carbohydrates and minerals such as iron. Hence, common bean is best suited for improving food security and incomes among the smallholders farmers arid and semi-arid lands due to their short maturity period, commercial potential and nutritional quality (Gichangi *et al.*,2012). This study will increase awareness among the small-holder farmers on the adoption of the drought tolerant bean varieties and importance of tillage practices in production of common beans. Moreover, the information will be helpful to the breeders in understanding the challenges underlying adoption of these varieties in semi-arid areas.

The primary source of agricultural water is rain. Most of total precipitation received is lost through evaporation and runoff or deep percolation. Improving water productivity under moisture limited conditions offer multiple gains to farmers by increasing crop yields and income (Gleick *et al*., 2011; Qadir *et al*., 2007). Vadez *et al*. (2007), reported plants adapt to soil moisture deficit by increasing rooting depth. Whitmore and Whalley (2009), attributed hydraulic distribution to method by which deep root systems supply plants with soil moisture. According to Namugwanya *et al*. (2014), this method is observed during the dry season where deep rooting system increased shallow soil moisture content through hydraulic lift by night, thus improve yield.

Despite the gains of this method, breeders have not given attention to this technique in breeding common bean varieties. Singh *et al*. (2013) attributed greater water challenge to increased population, climate change variability in precipitation and glacier melt. WUE in agriculture in drought prone areas, requires efforts from different research disciplines to develop new approaches in water conservation. This could contribute to alleviating poverty and improve food security in areas that are prone to drought and low soil fertility like Machakos County, Eastern Kenya. However, among the various techniques of improving productivity in drought prone areas, increasing water use efficiency is paramount. Bisht *et al*. (2016) reported high WUE crop to have greater yield compare to crops with low WUE.

1.4 Research objectives

1.4.1 Broad objective

This study seeks to improve in the cultivation of common bean in drought prone areas of Kenya through adoption of drought-tolerant common bean varieties that are efficient in water utilization.

1.4.2 Specific objectives

I. To gather cultivation information on drought-tolerant common bean varieties adopted by the small-scale farmers in Machakos County.

II. To determine the effects of tillage practices on water use efficiency and yield of different drought tolerant common bean varieties.

III. To determine the effects of drought-tolerant common bean varieties on water use efficiency.

1.5 Research hypothesis

I. Farmers' inclusion in the decision-making and selection of drought-tolerant common bean varieties will increase adoption of these varieties among small-scale farmers.

II. Different drought tolerant common bean varieties differ significantly in their water use efficiency.

III. Conservation agriculture will positively influence the water use efficiency and increase yield of different drought-tolerant common bean varieties in semi-arid areas of Machakos County.

1.6 Outline of the thesis

This thesis is composed of seven chapters which are structure as follows; Chapters one and two are on general introduction and literature review. Chapter three is on general material and methods of how the study was achieved from survey, experimental, data collection and analysis. Chapter four focus on assessing factors influencing adoption of drought tolerant common bean varieties in Machakos County. This was achieved by conducting a survey through a focus group approach. Chapter five looks at the effects of tillage practices on WUE and yields of different drought tolerant common bean varieties in Machakos County. This was achieved through experimental field work where varieties chosen by farmers from the research survey were tested. These four varieties were combined with three tillage practice in a 3×4 split-plot complete randomized block design. There were 12 treatments with the tillage practices the main plot factor and the varieties were the sub-plot factor.

The experiment contain about 4 blocks with 48 total plots containing 50 assessed tubes where neutron probe was let down for bi-weekly moisture reading and soil analysis was done on soil samples taken from the experiment site and nutrient status of the soil were determined while weather data on rainfall, temperature, humidity, and wind speed were collected from the meteorological station in Machakos Katumani and ETo was determine along with the WUE of each crop. Chapter six determines the WUE of different drought tolerant common bean varieties. This was achieved by the end of the cropping season (SR and LR), where crops were harvested and yields expressed over the ETo common bean to get the WUE. Chapter seven deals with the general discussion and conclusion of the study. This is the general summary of the entire thesis work.

CHAPTER TWO

LITERATURE REVIEW

2.1 Economic importance of common beans

Common bean is a crop rich in nutrients and is commonly cultivated in Sub-Saharan Africa, and is a significant diet, to rural and urban dwellers providing proteins, carbohydrates, essential elements and vitamins (Namugwanya *et al*., 2014). According to Beebe *et al*. (2013) and Broughton *et al.* (2003), the crop is mostly consumed by poor people who cannot afford meat and fish. Consumption of common bean in Eastern Africa varies by region whereas the consumption *per capita* is 66 kg year^{-1} in Rwanda, Kenya and Uganda (Broughton *et al*., 2003). Consumption is lower in Latin America, Colombia and Brazil at 4 and 17 kg year^{-1} (Beebe *et al*., 2013). According to (Adhikari *et al.*, 2016), the crop is an important food crop in Kenya and is ranked second after maize.

In terms of provision of calories, the crop is ranked number three apart from maize and cassava (Hillocks *et al.*, 2006). The crop is consumed almost every day as seeds and vegetable in various forms that is leaves and pods (Broughton *et al.*, 2003). Common bean crop has some health benefits ranging from colon, breast cancer and heart diseases (Hayat *et al.*, 2014). Moreover, common bean is mostly grown by small scale farmers especially women in areas considered marginal using few inputs under several cropping system. The crop has the potential both to reduce poverty and increase food security among the resource poor (Creamer, 2014). The land size under cultivation of bean crop has increase to one million hectares proving its importance (FAO, 2013). Common bean creates a firmed and promising medium of income for many rural dwellers, with value of sales now exceeding US$500 million annually (Akibode, 2011). Common bean plants also contributes to soil fertility (Zahran, 1999).

2.2 Distribution of common bean

In Africa, cultivation of the crop is widely spread in ten countries namely: Kenya, Uganda, Tanzania, Rwanda, Angola, Burundi, Democratic Republic of Congo, Malawi, Ethiopia and Madagascar (Tshilidzi *et al.*, 2016). In terms of land areas under cultivation of the crop in Africa, Kenya leads, proceeded by Uganda and Tanzania respectively. According to Benadatte & Nairobi, (2016), Malawi and Ethiopia rank eighth and ninth in terms of common bean production respectively. However, in terms of production, Uganda come first followed by Kenya with Tanzania taking its third position (Akibode, 2011). Yields of common bean are higher in Uganda compared to Kenya due to favorable biophysical environment such as weather condition (Katungi *et al*., 2009).

Cultivation of common bean in East Africa is done two times a year, during the long (LR) and short (SR) season running from March to April and from September to October, except in parts of Ethiopia where the main season is June to August (Keating *et al.,* 1988*;* Wortmann *et al.*, 1998). The wetter months in Ethiopia are June and August and are reliable for cultivation while March and April season is regarded as unreliable in bean production. The crop is mostly grown in sole cropping and intercropping system. Common bean is intercropped with other crops including maize, cassava, banana and other legumes (Allen *et al.,* 1998; Broughton *et al.*, 2003). Common bean cultivation is approximately grown in 74 percent in East Africa, 57 percent in Southern Africa respectively (Wortmann *et al.*, 1998). Rodríguez De Luque & Creamer, (2015), reported that in the Eastern and Western regions of Kenya, Common bean production globally in 2010 was approximated at 23,816,123 t, with 24.4 and 17.7% of the world production in Latin America, Caribbean (LAC) and Africa, respectively.

2.3 Climatic requirements for bean production

Common bean is an annual crop grown in a warm climate, optimally at temperatures of 18 to 24 °C at an altitude that range between 600 -1950 m above sea level in many tropical areas. During flowering, temperature should not exceed 30 °C. Increased temperatures of the above, leads to abscission of vegetative parts, low pod and yield loss. Maturation is delayed at below 20 °C creating empty pods to develop. Under rainfed conditions, the crop requires a minimum rain of about 400 to 500 mm, but an annual total of 600 to 650 mm is ideal (Reclamation, 2014), and well-drained soils with optimum soil pH between 6.0 and 7.5 (Williams, 2016). Soil type for common beans range from light to moderately heavy and to peaty (Rrg, 2015).

2.4 Constraints in common bean production in semi-arid regions

In semi-arid areas, the common bean is challenged by biotic and abiotic conditions (Highlights, 2008; Kimiti *et al*., 2009; Musoni *et al*., 2005). According to Odendo *et al*. (2004), disease is a factor that causes severe yield losses. More so, the pace of production for common bean has not been kept over the years due to drought, soil fertility and socio-economic constraints (Xavery *et al*., 2006). The biotic factors include pests and diseases while abiotic factors include climatic and edaphic constraints. The production of the crop in Semi-arid regions is constrained by drought which is defined as the cause of insufficient rainfall, erratic rainfall distribution and delay onset or early cessation of rains (Katungi *et al*., 2009). There is remarkable loss of common bean yield to drought irrespective of the variety as most of the cultivars grown are known to be of low levels of drought tolerance (Katungi, 2010). Drought affects up to 60% of bean production in semi-arid regions where it is endemic (Sciences, 2012).

Edaphic constraints also contribute significantly to yield loss of common beans. The notable elements of importance include N, P, and K that are limiting in tropical soils and are a major aspect of low soil fertility. Other factors leading to low soil fertility include low CEC, and higher soil pH (Wortmann *et al*., 1998). The bean plants exhibit poor emergence after being planted in such soils and eventually experience slow growth, stunted, yellowing, chlorosis, and delayed and prolonged flowering, excessive flower and pod abortion. The multiple problems results in severe yield loss (Singh *et al*., 2013).

2.5 Interventions in overcoming biophysical factors affecting production of common bean in Semi-arid regions

Breeding for common beans is a crucial programme undertaken by various researchers in the recent past as part of strategies to address drought and soil fertility. Work on breeding for drought tolerance have been through intraspecific crosses and there are future prospects of using interspecific crosses with sister species of the common beans especially those found in semi-arid or arid environments (Beebe *et al.*, 2013). Examples of these new advanced drought-tolerance bean varieties include *Mex 142, Kenya early, DNB 11-10, DSS 11- 04, DMC 11-13, DRK 11-12, DRM 11-14, DPC 11-05, DSR along with Katumani Bean 1 (KAT/B1), Katumani X69 (KATX69), Katumani X56 (KAT56),* and *Katumani Bean 9 (KAT/B9)* (Karanja *et al*., 2008), geared towards increasing income and food security in the drylands of Kenya.

2.6 Conservation agriculture

Another proponent is conservation agriculture (CA) that aims at conserving water and recycling of nutrients. CA is being adopted in the drought prone areas like Eastern Kenya (Marenya *et al.,* 2015). Micheni *et al*. (2014) showed that conservation agriculture practices, namely Zero tillage and furrow/ridges were found to increase the yield of common beans due to provision of extra soil nutrients and moisture. Conservation agriculture, leads to lower N release from soil organic matter followed with the wide C: N ratio due to retention of organic substrates (Naab *et al*., 2017). On moisture stress, CA has been proven to modify soil water dynamics such as infiltration, runoff and evaporation hence supporting crop production in drought prone areas (Giller *et al.*, 2011).

Conservation Agriculture, for resource-saving, is gaining acceptable profits together with higher production levels and concurrently conserving the environment (Kassam *et al*., 2009). This type of agriculture seeks to promote environmental friendly activities that preserve above and below-ground colony of micro and macro-organisms. Conventional tillage minimized and the use of agrochemicals and fertilizers are applied at an optimum and in a way and quantity that does not interfere with, or disturbed, the biological activities (Lehman *et al.*, 2015). De Vita *et al.* (2007), reported greater yield with zero tillage than conventional tillage on wheat yield. Conservation agriculture is an alternative form of agriculture that cut down on high cost of energy for poor farmers. For this reason, conservation tillage is becoming increasingly attractive to farmers because it clearly reduces production cost relative to conventional tillage (Kassam *et al*., 2010*).*

2.6.1 Basic principles of conservation (tillage) agriculture

Conservation agriculture (CA) revolves around three basic principles, namely minimal soil disturbance, soil cover with crop residues and crop rotation (Pedzisa, 2016). The first principle entails reducing excessive soil disturbance by mechanical means and sowing seedlings exactly into the undisturbed soil. Secondly, CA seeks to maintain year-round soil cover either by crops/cover crops or by residues from the last crop or both. Lastly, changing the order of crops and groupings, adjusted to local environment, and applying the right legumes; to sustained biodiversity above and below the soil, while providing nitrogen to the soil/plant system, and assist in doing away with increased in pest build-up (Kassam and Friedrich, 2011).

2.7 Conventional tillage

Cowan *et al*. (2008) define tillage as preparing seedbed for planting by plowing using a moldboard or animal drawn in cultivating or otherwise turning the soil. This practice loosens and aerates the soil, for deeper penetration of roots (Cowan *et al.,* 2008). Tillage checks weeds and incorporate organic matter, fertilizer and manure with the soil. However, tillage practice contribute to loss of soil moisture, increased water and wind erosion and it involves the use of more fuel (Cowan *et al*., 2008).

2.7.1 Mechanized systems

This is the mechanical manipulation of a soil in an entire field using a plough followed by one or more harrowing (Schmitz *et al*., 2015). The type of implement used determines the type of disturbance, the number of passes, soil and intended crop type. This is therefore, a method that leaves less than 30 percent ground coverage and usually involves the use of moldboard plough, disks, and chisels in tillage operations. It also loosens and aerates the soil for better and deeper roots penetration

2.7.2 Traditional tillage

This is the tillage practiced mostly by manual labour, using native tools which are few and simple, with cutlass being the most important and hoe which come in several designs depending on function (Schmitz *et al*., 2015).

2.8 Water use efficiency

Water use efficiency (WUE), has been defined in line with drought and plant performance when water becomes limiting (Ogawa and Yamauchi, 2006; Turner, 2004). In this context, WUE is being referred to as the long-term WUE instead of the instantaneous WUE which deals with immediate action or stomatal exchange of gases. In this case, WUE is discussed at whole plant level, season-long water use efficiency (WUE_{sl}, $mmol^{-1}$ $Cmol^{-1}$ H_2O) (Jones, 2004). However, WUE can be defined as the ratio of net gain in dry matter over a given period, divided by the water lost over the same period (Jones, 2004). That is why in this case, ET crop becomes very essential for computing WUE. For field applications, dry mater and water loss can be expressed in different ways. In physiological or biological sense, WUE_{sl} is usually regarded as the ratio of total biomass produced per unit of water lost by transpiration being referred to as transpiration efficiency (Jones, 2004). However, Agronomists referred to it as crop water use efficiency; that is measure of economic yield produce by transpiration or evapotranspiration (Jones, 2004).

Drought stress and climate change are major constraints encountered by common bean farmers in Africa. Mitigating this constraint requires the selection of resilient crop varieties that withstand drought threats to common bean production. Most of the bean cultivation occurs in land prone to water deficit causing yield losses (Lanna *et al*., 2016). As the world's population is increasing, there is a need to feed the growing number of people by the year 2050 thus imposing pressure on marginal areas for cultivation as well as fresh water and underground storage to increase production to feed future generations. Based on the staggering increase, there is a need to enhance breeders' capacity aimed at breeding for improved varieties that are resilient to these water deficient areas and more efficient in water use to improve productivity. In arid and semi-arid, most crops that are grown are rain fed (Wallace, 2000).

CHAPTER THREE

MATERIALS AND METHODS

3.1 Description of study site

The study was conducted in three villages, namely Kyamuluu, Kaathi and Mwania. The villages are located south eastern Machakos County between longitude 37°9'0" E to 37°39'0" E and latitude 1°27'0" S and 1°45'0" S (Figure 1). Ecologically it falls under agro-climatic zone IV, which is described as medium to marginal (Jaetzold *et al.,* 2006). Rainfall is bimodal with annual mean rainfall as 711mm whilst the average seasonal rainfall is 301mm for the long rains (March-May) and 283mm for the short rains (October-December). However, the short rains tend to be more reliable for crop production than the long rains (Kwena *et al*., 2017; Recha *et al.*, 2012). Temperature range between 17 and 24°C (Jaetzold *et al*., 2006). The mean potential evaporation is in the range of 1820 to 1840 mm per year (Karuma *et al.,* 2014).

However, like other areas of the semi-arid eastern Kenya, rainfall occurs in events of unpredictable intensity, with coefficients of variation in seasonal rainfall often exceeding 50% (Recha *et al.*, 2012; Keating *et al*., 2010). Therefore, the timing and relative lengths of each growing period vary substantially such that any delays in planting, particularly at the start of the wet season bring risks of significant losses in yield almost proportional to the time delay (Keating *et al*., 1992 ; Jewell *et al.,* 1994; Kinama *et al*., 2007). The first rains occur from March to May with a peak in April. These are referred to as the long rains. The second season falls in October to December with a peak in November and is also known as the short rains.

Predominantly, the area is covered by Lixisols derived from granitoid gneiss of the Basement System Complex. Unlike other areas of semi-arid Eastern Kenya, soils are deep to very deep, well drained, dark red to reddish brown, weakly structured and friable, with sandy and sandy loam near the surface (Karuma *et al.*, 2014). In semi-arid Eastern Kenya, soils are faced with fertility and slightly acidic in reaction. The cation exchange capacity (CEC) of these soils is generally low to very low (e.g. 7.8 cmol kg^{-1}), (Itabari *et al.*, 2013 and Composition *et al.*, 2016). The soils are often deep and well structured, allowing deep penetration of plant roots and a moderately good capacity to hold available water (Simpjol and Luhllfwa, 1996). The soil also exhibit high erodibility, surface capping under raindrop impact resulting in poor infiltration of rain water hence high runoff, serious erosion, and lose of nutrients on many of the steeper cropland sites (Simpjol and Luhllfwa, 1996).

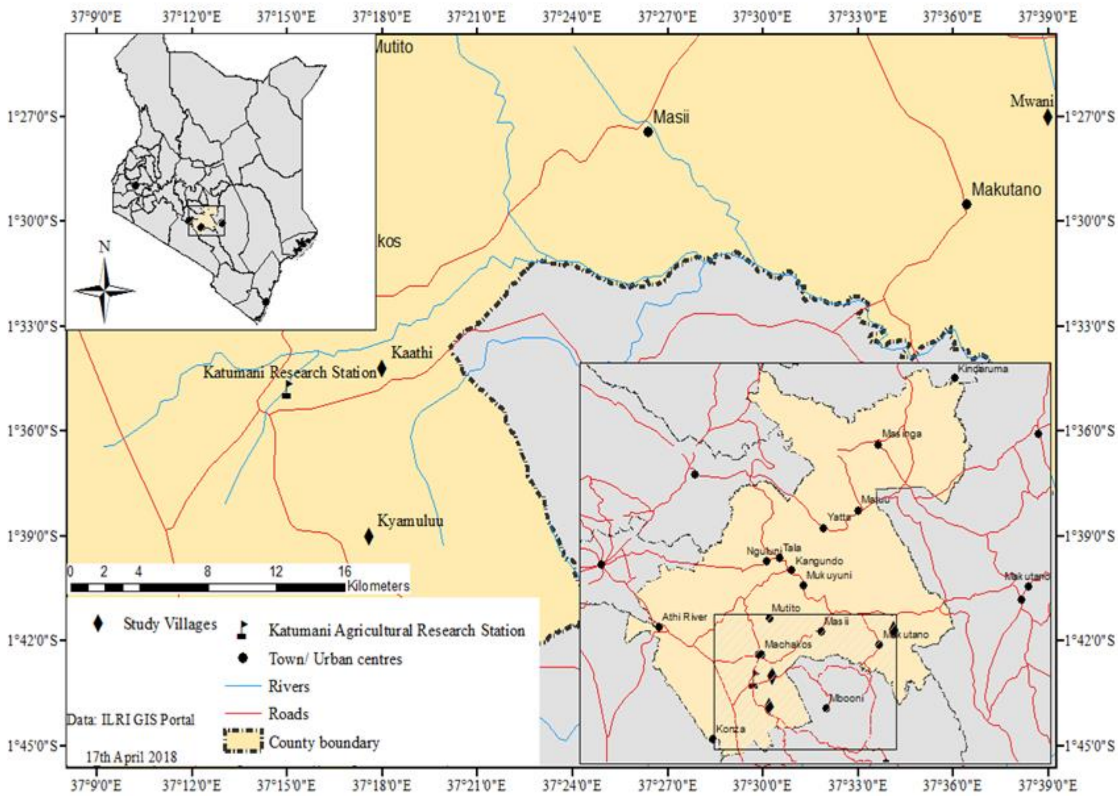

Figure 3.1: Map of the study area

The landscapes consist of flat to hilly elevations with relief variation of 10-20m. The slopes are straight with gradient range between 2% and 20% (Kutu, FR, 2012). The main agricultural production enterprise in the area is mixed crop-livestock production systems with varying degrees of integration. Main crops are maize, beans, pigeon pea, cowpea, and sorghum.

3.2 Data collection

3.2.1 Survey for the adoption of drought tolerant beans varieties in Machakos County

The information on adoption of drought tolerant varieties in Machakos County and the factors underlying their adoption or lack of adoption were obtained through focus groups approach from three villages namely Kaathi, Mwania and Kyamuluu villages respectively. The data described below were collected using videos and open-ended questionnaire, targeting at least twenty respondents per location.

The varieties of common beans being cultivated, (b) Reasons for selecting those varieties of common beans, (c) information on the availability of drought tolerant common bean varieties, (d) challenges facing production of common beans in the regions, (e) farmers' details such as education level, sex, marital status and farm sizes in acres were from the farmers through the focus group discussion.

3.2.2 Experimental design, layout and agronomic activities

The experiment was conducted at the Katumani Research Station, in Machakos County, Kenya. The treatments were arranged in a 3 × 4 Split-plot arrangement in RCBD. The land size of the experimental area was 61 m × 18 m. Plots size were 2 m × 8 m and rows between plots were 0.75 m. The sub-plots were separated by a 1m path way and the four blocks were separated by 3 m × 2 m path ways respectively. The total plots were 48 along with 48 access tubes drilled and installed firmly in the soil at a depth of 1m or whichever shallower for moisture reading using the Neutron probe 503DR Hydro probe. Additional two tubes were placed outside the experimental plots for calibration purposes.

There were three tillage practices replicated four times. Each sub-plots containing the tillage practices (CT, MT and ZT), were separated by 1m path way and 0.75 m row and each block was separated by 3 m × 2 m path ways. Four drought-tolerant common bean varieties GLPX92, KATB1, KATX-56 and KATRAM identified by the farmers in the study site, three tillage systems; conventional tillage (CT), minimum tillage (MT) and zero tillage (ZT) combined as follows: GLPX92 in combination with CT, GLPX92 in combination with MT, GLPX92 in combination with ZT, KATB1 in combination with CT, KATB1 in combination with MT, KATB1 in combination with ZT, KATX-56 in combination with CT, KATX-56 in combination with MT, KATX-56 in combination with ZT, KATRAM in combination with CT, KATRAM in combination with MT, KATRAM in combination with ZT. These varieties were selected by farmers through a survey conducted in the study area through assistance of local leaders and extension officers. Three seeds were planted per hole but later thinned to two seedlings after germination to reduce competition for nutrients and increase proper growth. In the conventional tillage, the land was ploughed using chisel and two oxen to break the hard pan a month before planting.

3.2.3 Data collection and processing

Total available water content (TAWC) was taken at planting, vegetative, flowering and podding stages using Neutron probe 503DR Hydro probe. This was calibrated using the gravimetric water content (g/100 g soil) by plotting a graph of neutron counts against gravimetric water content. A line of best fit was developed with $y=mx + c$ equation; Where y is the gravimetric water content, m is gradient, x is the neutron counts and C is the y intercept in this case zero interception. Therefore, all the neutron probe readings were converted into gravimetric readings by multiplying with m (gradient of the line of best fit). Finally, the gravimetric water readings were converted into volumetric water content using the Equation 3.1 (Tobergte and Curtis, 2013).

$$\Theta = \omega\rho_b \div \rho_w \qquad [3.1]$$

Where: $\boldsymbol{\rho}_b$ - soil bulk density, $\boldsymbol{\rho}_w$ - water density (g/cm^3), Θ - volumetric water content, ω - gravimetric water content.

The soil field capacity and permanent wilting point were determined from soil samples collected in the field from the Katumani Research station and analyzed at the University of Nairobi Soil Science Laboratory before planting. Soil analysis were carried out on total N, available P, soil pH, total K, Ca, Mg, Mn and Al before planting. These were done to know the nutrient status of the soil so that they do not serve as factors hindering production. Total N and available P were analyzed using Kjeldahl and Olsen methods respectively. Soil pH was done in the ratio 1:2.5 soil to water. Total cations were analyzed using Mehlich method and determined using Atomic Absorption Spectrophotometer. All procedures were described according to (Okalebo *et al*., 2002).

Weather data comprised of solar radiation, air temperature, rainfall, humidity and wind speed for the Katumani station on monthly basis. All these were obtained from Katumani weather station Machakos County. Minimum and maximum thermometers, gun ballani, hygrometer and anemometer were used for measurement of air temperatures, solar radiation, humidity and wind speed respectively. The weather data were used in computation for the ET common bean using the FAO Pennman-Monteith Formula as illustrated in Equation 3.2 (Allen *et al*., 1998; Hsiao *et al*., 2012; Cai *et al*., 2007);

$$ET_\circ = \frac{0.408Sa\,(R_n - Gd) + \gamma \frac{900}{T + 273} v_{2m}(e_s - e_a)}{Sa + \gamma(1 + 0.34v_{2m})} \qquad [3.2]$$

Where: ET_O - Reference evapotranspiration, R_n - Net radiation at the crop surface in (MJ/m^2 per day), Gd -Soil heat flux density (MJ/m^2 per day), T - Mean daily temperatures at 2 m height (°C), V2m - wind speed at 2 m height (m/sec), e_s - saturation vapor pressure (kPa), e_a - Actual Vapor Pressure (kPa), e_s-e_a - Saturation vapor pressure deficit (kPa),Sa -Slope saturation vapor pressure curve at temperature T (kPa/°C), $\boldsymbol{\gamma}$ -Psychrometric constant (kPa/°C).

Water use efficiency (WUE) was computed using data on grain yields and ET of common bean obtained in Equations 3.2 and 3.4, using Equation 3.3;

$$WUE = \frac{yields}{ET\ crop} \qquad [3.3]$$

3.2.4 Determination of biomass and grain yield

Biomass was collected after harvesting at the maturity stage of the crop from the inner rows after discarding the outer two rows from all four sizes of each experimental plot. Pods were extracted and the biomass was weighed per plot and effects of tillage practices on the biomass were determined as per weight.

Grain yield was collected at the maturity stage of the crop after harvesting and dried at 13% commercial value and weighed. Harvested grain yield were converted to grain yield per hectare using Equation 4;

$$\frac{Grain\ yield\ (kg)}{ha} = \frac{Grain\ yield}{effective\ harvested\ area\ m^2} \times 10{,}000\ m^2 \qquad [3.4]$$

3.2.5 Total available water content (TAWC)

Total available water content (TAWC) was taken at planting, vegetative, flowering and podding stages using Neutron probe 503DR Hydro probe. This was calibrated using the gravimetric water content (g/100 g soil) by plotting a graph of neutron counts against gravimetric water content. A line of best fit was developed with y=mx + c equation. Where y - gravimetric water content, m - gradient, x - is the neutron counts and C is the y interception in this case zero interception. Therefore, all the neutron probe readings were converted into gravimetric readings by multiplying with m (gradient of the line of best fit). Finally, the gravimetric water readings were converted into volumetric water content using Equation 3.1 (Tobergte and Curtis, 2013).

The soil field capacity and permanent wilting point were determined from soil samples collected in the field from the Katumani Research station and analyzed at the University of Nairobi Soil Science Laboratory before planting.

3.2.6 Soil analysis

Soil analysis were carried out on total N, available P, soil pH, total K, Ca, Mg, Mn and Al before planting. These were done to know the status of the soil so that they do not serve as factors in hindering production. Total N and available P were analyzed using Kjedhal and Olsen methods respectively. Soil pH was done in the ratio 1:2.5 soil to water. Total cations were analyzed using Mehlich method and determined using Atomic Absorption Spectrophotometer. All procedures were described according to (Okalebo *et al*., 2002).

3.3 Data analysis

Data obtained from the cross sectional survey of drought tolerant common beans varieties, Information on domesticated common bean variety, reasons for their selection, information on their availability, challenges facing their production and farms' details were sorted, coded and analyzed using the SPSS version 21.0. A two-way ANOVA was carried out on the grain yield data and WUE using Genstat 14 edition. The experimental model followed the 3×4 Split-plot randomized complete block design. Statistical significance was determined at $P \leq 0.05$. Means were separated using Duncan Multiple Range Test.

CHAPTER FOUR

Assessing factors influencing adoption of drought tolerant common bean varieties: A case study of Machakos County, Kenya

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Abstract

In Kenya, one of the major and cheap source of protein is bean (*Phaseolus vulgaris* L.). The crop is consumed in almost every household on a daily basis due to its cheapest nutritional source. Machakos County, where the survey was carried out during 2016/2017 cropping season, experienced crop failures and low bean production due to drought, spice rainfalls and low soil fertility. This study seeks to assess the adoption of farmers to drought tolerant common bean varieties in Machakos County. Data was collected from three locations namely; Kyamuluu, Kaathi and Mwania villages in Machakos County. The selected farmers interviewed using a focus group approach. Open-ended questionnaires were administered to each farmer, filled in, and photos for each group were taken during each session. From each of the three villages of Kyamulu, Kaathi and Mwania, 16, 11 and 11 farmers were interviewed, respectively totalling 38 farmers. The selection was based on those who made themselves available at the time of the focus group discussion. Data was analysed using statistical package for the social sciences (SPSS 21.0.0.0) for descriptive analysis while Pearson correlation coefficient was used to determine the relation among the variables and logistic regression coefficient was used to determine the strength between the independent and dependent variables. Results obtained showed that 55% of the farmers obtained certified seeds for production while 45% are still using uncertified seeds. A regression and correlation analysis showed that preference of KATX56, KAT/B1, GLPX92 and KATRAM bean varieties led to an increased adoption by most farmers due to seeds availability by Government, the Dryland Seed Company (DLSC), Agro-dealers and Research Institutions. Most importantly, 55% of the farmers attributed their adoption of KATX56, GLPX92, KAT/B1 and KATRAM based on yields, market demand and WUE. However, research is

required to document the WUE of the various drought tolerant bean varieties to increase the rate of adoption and decision making process among farmers during drought.

Key words: *Phaseolus vulgaris*, water use efficiency (WUE), drought tolerant, climatic conditions and adoption.

4.1 Introduction

Common bean (*Phaseolus vulgaris L.*) is an important legume for human consumption and is second to maize as a food crop in Sub-Sahara Africa (Beebe, 2012; Broughton *et al.,* 2003; Mwang'ombe *et al*., 2008). Despite the importance of the crop, the productivity of common bean has been decreasing. According to Mwang'ombe *et al*. (2008), biotic and abiotic constrains as well as low external inputs like fertilizers are believed to have reduced the yield of common bean by up to 25% of the potential yield. In addition, erratic and poorly distributed rainfall, use of poor genetic materials, pests and low soil fertility contribute to the low yield (Kavoi *et al.*, 2016). However, among the efforts to increase bean production in semi-arid areas, the adoption of improved early maturing and drought tolerant genotypes is a viable option (Katungi *et al*., 2009).

In Kenya, several research centers including Centro International de Agricultura Tropical (CIAT) and the National Drylands Research Centre in eastern part of Kenya have been producing improved bean varieties and sensitize farmers on innovative production methods in the arid and semi-arid areas. As a result, drought tolerant bean varieties like the Katumani Bean series were developed Kitonyo *et al*. (2013), but the supply has not reached outside semi-arid localities as seed demand remain unmet (Buruchara *et al.*, 2011; Rubyogo *et al*., 2010). This has led to approximately 63% of farmers in eastern Kenya adopting the improved bean varieties with majority of them growing more than one varieties on their farms while the rest of the farmers grow only one type of improved bean for domestic and commercial purposes (Value and Analysis, 2013). Because of the high demand and market value of beans, farmers have abandoned growing other unprofitable crops for bean and are keen to adopt the improved varieties (Value and Analysis, 2013). Despite the adoption of new varieties by farmers, common bean productivity in Kenya remains one of the lowest in the region (FAO, 2013; Enid *et al*., 2015).

Production of beans can easily be adopted by small-scale farmers in semi-arid areas due to preference, economic potential as well as its short maturity period which permits production when rainfall is erratic (Katungi *et al*., 2010; Gichangi *et al*., 2012).This study seeks to document information on the adoption of drought tolerant common bean varieties in Machakos County in Kenya and the factors underlining their adoption or lack of adoption by the small-scale farmers, the variety adopted and reasons for selecting those varieties. Information on the availability of drought tolerant bean varieties and the challenges facing bean production. Understanding of these issues, by breeders and stakeholders, as well as the involvement of smallholder farmers in the selection of varieties based on their preference attributes, will increase production of beans.

4.2. Materials and methods

4.2.1. Study Area

The study was conducted in Machakos County between longitude 37°9'0" E to 37°39'0" E and latitude 1°27'0" S and 1°45'0" S (Figure 3.1). Ecologically it falls under agro-climatic zone IV, which is described as medium to marginal (Jaetzold *et al.,* 2006). Rainfall is bimodal with annual mean rainfall as 711mm whilst the average seasonal rainfall is 301mm for the long rains (March-May) and 283mm for the short rains (October-December). However, the short rains tend to be more reliable for crop production than the long rains (Kwena *et al*., 2017; Recha *et al.*, 2012). Temperature range between 17 and 24°C (Jaetzold *et al*., 2006). The mean potential evaporation is in the range of 1820 to 1840 mm per year (Karuma *et al.*, 2014).

Soils are deep to very deep, well drained, dark red to reddish brown, weakly structured and friable, with sandy to sandy loam texture predominantly, and are classified as Lixisols (Karuma *et al.*, 2014). The soil also exhibit high erodibility, surface capping under raindrop impact resulting in poor infiltration of rain water hence high runoff, serious erosion, and lose of nutrients on many of the steeper cropland sites (Simpjol & Luhllfwa, 1996). The main agricultural production enterprise in the area is mixed crop-livestock production systems with varying degrees of integration. Main crops are maize, beans, pigeon pea, cowpea, and sorghum.

4.2.2 Sampling method and data collection

Purposeful sampling method was carried out. Three locations were sampled based on the regions where common beans are mostly grown in Machakos County and these locations included: Kyamuluu, Kaathi and Mwania, villages where the Mbilini self-help group, Green shade self-help group and the Kyamuluu Tree Nursery group were interviewed, respectively. From each location, a focus group approach was carried out such that each farmer was presented a questionnaire and the questions were discussed and then later answered by each of the farmer. This process was carried out on separate days as per the meeting time of each group and location. This approach was used as a means to easily access these farmers outside of the planting season when they are engaged with tree nursery activities to up keep their families until the next planting season

Plate 4.1: Focus group discussion with farmers in Machakos County

begins. A total of 38 farmers were interviewed from three villages as follows; Kyamuluu village -16 farmers, Mwania and Kaathi villages - 11 farmers each. The area chiefs together with the extension staffs helped in mobilizing the community and partially in data collection. Due to language barriers, the local leaders helped in the translation.

Information on the socio-demographics, Bio-data: farmers' details such as education level, sex, marital status and farm size in acres were from the farmers through the open and close ended questionnaire. Crops being domesticated and production constraints, cropping systems in Machakos County, challenges facing production of common bean in the region were recorded. Information on the availability of drought tolerant common bean varieties and factors underlying adoption of drought tolerant varieties was obtained through focus group's approach. The data described above were collected using photos snapping of farmers .and combined open ended questionnaire; targeting at least thirty respondents per location but due to personal engagements of respondents outside of the farming season, a total of thirty eight farmers were accessed from the three locations to partake in the focus group discussion.

4.3 Data Analysis

Descriptive statistics was conducted for data collected on farmer distributions of farmers, drought tolerant common bean varieties; information on the domesticated common bean variety, reasons for their preference , information on their availability, challenges facing their production and farmers. Bio-data was sorted, coded and analysed using the Statistical Package for the Social Sciences (SPSS 21.0.0.0.) version (Roldan-Valadez *et al*., 2015). Bivariate analysis was carried out with the same SPSS 21.0.0.0. (Roldan-Valadez *et al*., 2015). Pearson Correlation Coefficients were used to investigate the correlative relationships of socio-economic variables: gender, education, farmers' awareness of drought tolerant common bean varieties, yield per acre, production constraints and sources of information on growing DTCBV. Only variables that were linked to this study from the focus group discussion were used in the analysis. A logistic regression analysis was also carried out using the Statistical Package for the Social Sciences (SPSS 21.0.0.0.) version to determine which variable among the independent variables were closely related to the dependent variable: type of drought tolerant bean varieties, yield per acre, awareness on variety types, sources of information and seeds sources as related to the dependent variable: preference to determine the strength of the relationship that increased the adoption of farmers to the these drought tolerant varieties.

4.4 Results and discussions

4.4.1 Socio-demographics characteristics of farmers

Most of the farm household dwellers in Machakos County were headed by males (90%), most of whom (40%) had an average age of between 20 - 50 years Table 4.1. This implies that age of the households' heads described the sample size of the population as observed by Kecskemeti, 1996. Majority of the farmers above 20 years were married (82%) and had more children than their younger counterparts as indicated by the positive correlation between number of children and age of the household heads Table 4.5. In the study area, the rest from 20 years (5%) were not married but own homes and farm lands inherited from their parents or grandparents. The proportion (47%) of farmers who had attained secondary level education, indicate that the majority of the farmers had prior knowledge and have adopted planting these drought tolerant varieties.

The significant relationship found between education level of the household heads and awareness of drought tolerant bean varieties Table 4.5, implies that probability of increased adoption depends on the level of education. This is in agreement with Amaza *et al*.(2017), who reported a direct relationship between improve maize varieties (IMV) adoption and educational status. Gichangi confirmed that the ability of farmers to obtain, process and use information relevant to production is increased by education. Conversely, the proportion of household heads (24%) who have not accessed or at least had informal education account for farmers who still subscribed to their traditional technology and are using recycled seeds from the previous seasons of which the viability chances are not known and are still having challenges adopting modern technologies which shows a non-adoption factor and reduction in production. The negative but significant relationship between education level and gender of the household heads indicate that adoption of these new varieties by farmers who have not attained any form of education is still a problem and a factor to food insecurity in many rural household.

Table 4.1: Demographic characteristic of respondents

		(%)	Mean (SD)
Household head	Male	89.5	
	Female	10.5	
Gender	Male	57.9	
	Female	42.1	
Age (years)	20-40	39.5	
	40-50	39.5	
	50-70	10.5	
	70-90	10.5	
Marital status	Married	81.6	
	Divorced	2.6	
	Separate	2.6	
	Single	5.3	
	Widow/widower	7.9	
Education level	Primary	26.3	
	Secondary	47.4	
	Tertiary	2.6	
	Informal	23.7	
Number of children	2-3	15.8	
	3-4	52.6	
	>4	31.6	
Occupation	Civil job	10.5	
	Farming	81.6	
	Casual	7.9	
Average family size			6.4 (1.15)
Average land size			1.42 (0.50)
Land tenure	Communal	100	

Note: Values in parenthesis represent the standard deviation of the means.

4.4.2 Crops being cultivated and production constraints

Generally pulses in eastern Kenya serve as a means of income and food security for rural household as shown in (Table 4.2). Due to the semi-arid nature of Machakos County Eastern Kenya, production of the crop is faced with several constraints such as biotic and abiotic factors, whereas drought (34%) (Table 4.2) was considered a major abiotic factor, with low fertility biotic factor exacerbating the problems (Ngugi *et al.*, 2011). Farmers are forced to engage in mixed cropping systems to get food on the table for the household and maximized the resources that are in sight hence avoiding total crop failures. This according to (Hopma, 2015), implies the food structure production deficit of several staples in Kenya. Almost all farmers in the study area produce several crops as coping mechanism to drought.

As a result of this, researchers have worked over time to generate improved drought tolerant bean varieties for improvement production and productivity. However, many varieties have been disseminated by KALRO, the Ministry of Agriculture, and Dryland Seeds Company amongst other organizations in the study area. However, despite the production constraints faced by farmers, 85% of them are still being involved in mass production of this crop due to its important role in household up keep and income based as shown by the 53% increase of farmers who grow bean than other crops (Table 4.2).

According to Value and Analysis (2013), 58% increase in male involvement in pulse production in Machakos County, is as a result of the continuous increased in prices of bean hence leading to higher income of these farmers. Despite, the tremendous production of various crops by household, there is still some production constraints like disease and pests, competition for fodders between both wild and domesticated animal like cattle competing for crops they have access to under such semi-arid condition. Inputs and drought (34%) exacerbating the problem as being the major contributor to crop failures in eastern Kenya (Hopma, 2015), and this is being experienced almost on an annual basis.

Table 4.2: Crops being cultivated and production constraints

	Crops	%
Crop grown	Green gram	2.6
	Cowpea	5.3
	Dolicos	5.3
	Pigeon pea	7.9
	Maize	26.3
	Bean	52.6
Production constraints of bean	Inputs (Seeds &fertilizers)	13.2
	Blight (fungal)	15.8
	Pests	15.8
	Wild and domestic animals	21.1
	Drought	34.2

4.4.3 Challenges facing production of common bean in the region

Most of the respondents interviewed (71%) were members of some financial institutions and had savings with commercial banks while others (29%) were not members of any financial institution and had no savings at all Figure 4.1. Although members of these financial institutions could access credits, majority of them (82%) complained of high interest rate, while 3% of them did not need loans. Whereas, others (11%) feared taking loans and the rest (5%) lacked security accessing loan Figure 4.2. These challenges could probably be the reason for which most of the farmers fear to take loan. In sub-Saharan Africa, older farmers and their younger counterparts have difficulties accessing loan from financial institutions due to high interest rate and fear of forfeiting their properties to these financial institutions (Aryeetey, 1998).

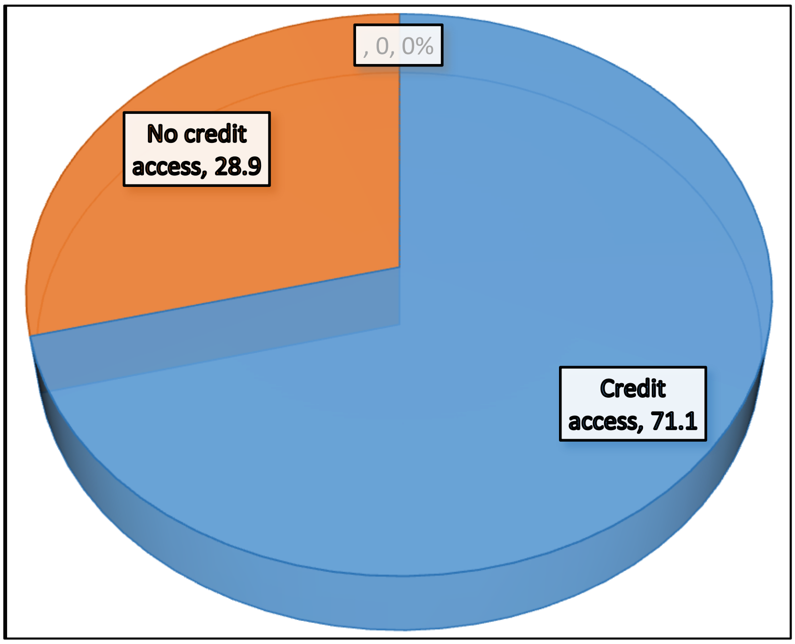

Figure 4.1: Farmers with credit access and those without credit access

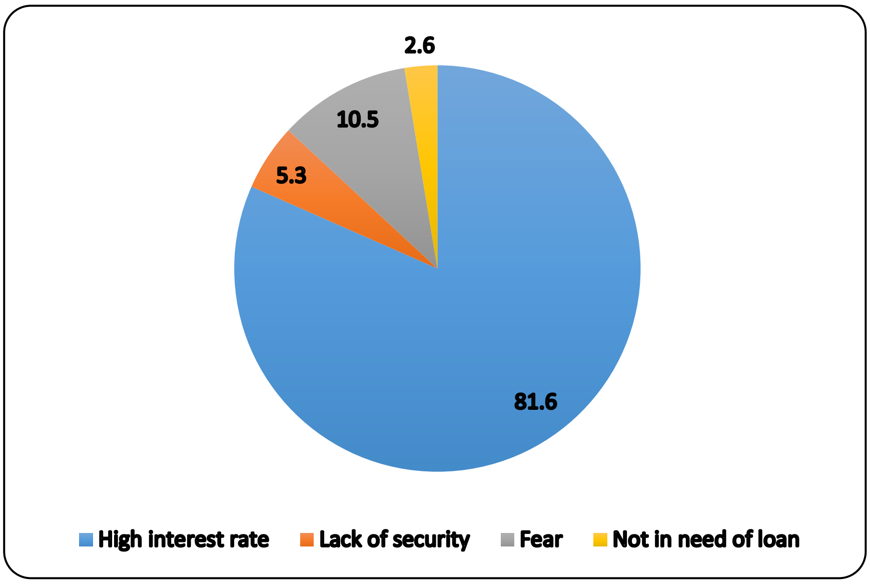

Figure 4.2: Proportion of farmers with credit access constraints

4.4.4 Information on the availability of drought tolerant common bean

From the thirty eight respondents interviewed, 30% obtained information from Ministry of Agriculture/KALRO, and another 30% relied on farmers' experience by recycling seed from the previous harvest. While 26% of farmers got information from the Research

Organization, the rest (16%) got information from the non-governmental organizations (NGOs) (Table 4.3). The common bean choice varies among farmers within a given locality and the integration of these varieties is based on production attributes which influence the choice of these varieties as indicated in Table 4.3. Of the respondents interviewed, majority (32%) preferred KAT X56 and (26%) GLPX92, (24%) KAT/B1 and (18%) preferred KATRAM due to their drought tolerant attributes. However, these results shows that farmers in the study area were knowledgeable about these drought tolerant bean varieties as indicated in Table 4.3. From the negative correlation of gender and sources of information, it is implied that older farmers were more likely to stick to the use of traditional farming methods as compared to their younger counterparts who preferred modern methods of farming.

However, sources of information on the availability of common bean among farmers, influences the choices of varieties within a given locality and the integration of these varieties is based on production attributes as shown by the positive relationship between education level and awareness of drought tolerant common bean varieties implies that awareness creation and the application of the knowledge acquired is more likely to increase adoption among farmers. Elsewhere in Uganda, Nankya *et al*. (2017) in a study "Yield Perceptions, Determinants and Adoption Impact of on Farm Varietal Mixtures for Common Bean and Banana in Uganda" agrees with results of the study that awareness creation increase adoption among farmers. Work done by other researchers and results from this study indicate that farmers in Machakos had adequate information on the availability of drought tolerant common bean varieties which is likely to increase adoption.

Table 4.3: Information sources on seeds availability, preferred varieties and reasons for preference

	Responses	
Information source of DTCBV	Farmers experience	28.9
	Research Organization	26.3
	NGOs	15.8
	Ministry of agriculture/KALRO	28.9
Preferred varieties	KATRAM	18.4
	KAT/B-1	23.7
	GLPX92	26.3
	KAT X56	31.6
Reasons for preference	High yielding & highly selling	50
	WUE and high yielding	50

4.4.5 Preference and factors underlying adoption among respondents

Most (50%) of the respondents preferred KATX56 followed by GLPX92, KAT/B1 and KATRAM (Table 4.3). This percentage (50%) of respondents said their preference is based on high grain yielding and high selling and WUE of these varieties. But preferences of the farmers were confined in the order of importance to this study. Moreover, the significant but weak relationship (-0.38) between gender and education level of the household(Table 4.4), implies that there is still a problem of education among the gender of the household especially with the proportion of respondents that have not received any form of education and are comfortable with their traditional technology. According to Indimuli, (2013) lack of education hinders the ability of farmers to perceived, interpret, and make use of modern technology. Additionally, sourcing and understanding information on growing of these drought tolerant bean varieties was a problem for some of the farmers probably due the lack of education hence yield per acre was affected due to the lack of technical knowhow base on their refusal to incorporate new knowledge on the production of these varieties with drought and fertility exacerbating issue.

However, the correlation between level of education and awareness of drought tolerant common bean varieties (DTCBV) (0.72) (Table 4.4) implies that the greater proportion of respondents with formal or informal education, were aware of the existence of these drought tolerant bean varieties and were knowledgeable and could interpret their usage than their other counterparts who were not educated. Moreover, based on the information received from the relevant authorities or research institution, respondents in this making use of the information they had on growing these drought tolerant common beans the various types as well as their production constraints under extreme circumstances, the preference and adoption of these varieties will be increased among the farmers. Elsewhere in Southern Ethiopia, Sheikh *et al*., (2017) reported that farmers preference was based on yield and yield attributing trait with earlier maturity which agrees with result from this study. In other research, farmer's preference was attributed to cooking time, colors, size of grains, number of grains, early maturity and rate of selling.

Table 4.4: Correlation among socioeconomic characteristics

	Gender	Education level	Aware of DTBV	Yields/acre	Production constraints	Sources of information	Information on growing DTBV
Gender	-						
Education level	-.382**	-					
Aware of DTBV	-0.179	.719**	-				
Yields per acre	0.146	-0.154	-0.151	-			
Production constraints	-0.171	0.085	0.028	-0.083	-		
Sources of information	-.322*	0.163	-0.086	-0.193	.448**		
Information on growing DTBV	-.278*	-0.128	-0.24	-.459**	0.064	.290*	-

**. Correlation is significant at the 0.01 level and *. Correlation is significant at the 0.05 level. DTBV=drought tolerant bean varieties, KALRO = Kenya Agriculture and Livestock Research Organization, DTCBV= drought tolerant common bean varieties, NGOs= non-governmental organization

A regression analysis was conducted to determine the factors influencing adoption of drought tolerant bean varieties by respondents of the household in the study area (Table 4.5). There was a perfect relationship observed between the preference and type of drought tolerant bean varieties grown (P = 0.000) with a positive coefficient and significant level at 5%, which implies that preference of these improved varieties by farmers will increase adoption as long as drought and other production constraints continue to be prevalence. Similar trend was also observed between preference and varieties types aware of at P = 0.000 though, significantly correlated, it had a negative coefficient which implies that in the study area, the more awareness is increased among farmers, the greater the rate of adoption to these drought tolerant varieties. This is in line with priori expectation Amaza *et al.* (2007), which suggest that the more experienced the farmer, the higher the rate of improved varieties adoption. It also indicate that the level of education and sensitization of farmers on these new varieties will increased the adoption of farmers to these varieties.

However, Elias *et al*., (2017) reported that there is a need to give emphasis to participatory research, which is farmers' inclusive, technology preference criteria and priorities seriously. Goa and Kambata, (2017) stated that farmers have their own preference criteria. However, when these preference criteria are disregarded by policy makers and breeders, it creates a propensity for farmers lacking confidence in such varieties because, being front liner in the production chain, they wouldn't want to risk their capital and labor in something they do not trust. In such medium to marginal area like Machakos County that is so hilly with erratic rainfall and annual drought occurrence, the involvement of all actors using this approach will make adoption beneficial and successful. Gichangi *et al*. (2012) reported the lack of trust in the improved varieties as a result of mismatch in preference criteria of farmers could be the reason for the usage of recycled seeds from the previous season.

Table 4.5: Regression among type of drought tolerant bean varieties grown, yield per acre, varieties types aware of, sources of information and sources of seeds

	Unstandardized coefficients B	Std. Error	Standardized coefficients Beta	T	Sig
(Constant)	1.714	0.322		5.326	0.000
Type of DTBV grown	0.425	0.082	0.647	5.215	0.000
Yield per acre	0.002	0.183	0.001	0.013	0.99
Varieties types aware of	-0.579	0.065	-0.964	-8.905	0.000
Sources of information	-0.006	0.167	-0.004	-0.073	0.971
Sources of seeds	0.007	0.035	0.017	0.187	0.853

a. Dependent Variable: Preference

4.5 Conclusions and recommendations

There exist drought-tolerant varieties that farmers are currently growing in Machakos County. However, because of production constraints, farmers preferred mixing drought-tolerant bean with other crops and also keeping animals on a minimum land size of 1-2 acres to avoid total failure of crops and food insecurity. Farmers acquired varieties seeds from relatives, other farmers, and research organization or from the local markets. Farmers are highly devastated by the occurrence of drought during the planting season, hence leading to farms abandonment.

There is a need for Government and research organizations to see farmers as stakeholders in the front line of the production chain by including their preference technology to improved bean varieties. Government should rejuvenate the extension services to work in line with the research organizations in getting quality and affordable seeds to farmers on time to enhance production of common bean. Extension agents, should work closely with meteorological stations in disseminating weather forecast information to farmers in preparing them for harsh climatic conditions. They should also be able to provide mitigation strategies to avoid food insecurity within the household in rural areas of semi-arid regions.

CHAPTER FIVE

Effects of tillage practices on water use efficiency and yield of different drought tolerant common bean varieties in Machakos County, Eastern Kenya

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Abstract

As world population increases, the need to feed this increasing population by the year 2050 is rising with marginal areas been cultivated to address these needs. This study seeks to compare effects of tillage on water use efficiencies (WUEs) and yields of drought-tolerant bean varieties in Machakos County using three tillage systems: conventional tillage (CT) done with chisel mounted on oxen for ploughing while minimum tillage (MT) and no-till (NT) were done using hoes to dig directly where seeds of four varieties were planted in 4 × 3 Split-plot randomized completely block design replicated four times. Erosion was negligible due to land slope flatness while actual ET crop was derived using meteorological data from 2016 and 2017 cropping seasons. Data were subjected to two-way analysis of variance (ANOVA) using Genstat 14th edition software statistical package at alpha 0.05. Duncan Multiple Range Test (DMRT) was used to separate means. Above-ground biomass and grain yield were harvested from the inner rows after discarding the outer two rows from all size of each experimental plot and weighed for total biomass and grain yield. Results indicate that interaction between tillage and seasons significantly influenced biomass and grain yield WUEs with GLPX92 yielding the highest in CT, MT and ZT though insignificant under the SR drought event, but under the LR favorable season GLPX92 yield decline with NT, CT and MT. These results suggest interactions of conservation tillage and seasons as the best option for production during favorable seasons and conventional tillage during drought events.

Key words: water use efficiency (WUE), erodibility, Conventional tillage, Minimum tillage, No-till, short and long rains, climate change and drought

5.1 Introduction

There is a growing concern of the increasing world population and the need to secure food security through a proper soil management strategy, which demands identification of an environmental friendly and crop yield sustainable system of tillage (Busari *et al.*, 2015 and Dumanski, 2015). Tillage, being defined as the mechanical manipulation of the soil for the purpose of crop production (Schmitz et al., 2015). However, tillage process significantly affects the soil characteristics such as soil water conservation, soil temperature, infiltration and evapotranspiration processes (Busari *et al.*, 2015). The art of tillage, can also be used as a soil management practice, to enhance cropping systems, influence water use efficiency (WUE) of crop in semi-arid environments as well as plant population in temperate and humid environments and nutrients management practices and water availability (Hatfield *et al.*, 2001; Mwehia, 2015) .

As the world is experiencing increasing population, so is the increasing demand for food hence, the need to open more lands arises. This must be done in such a way that soil degradation is avoided in that, the soil is prepared to serve as a sink rather than a source of atmospheric impurities. However, it is based upon the avoidance of the soil being a source of atmospheric pollutants that conservation tillage along with some complimentary practices such as soil cover and crop diversity. Kaumbutho *et al.* (1999) argues that conservation tillage is a component of conservation agriculture (CA). Hatfield *et al.*, (2001) propended that conservation tillage system can increase water use efficiency by 25-40%. However, little information on how conservation tillage influences the water use efficiency (WUE) of drought tolerant crops with short maturation period, such as beans is limiting our understanding on the importance of such practices in improving the production of drought tolerant common bean varieties. Despite these limitations, conservation tillage is still efficient in the maintenance of surface soil cover through retention of crop residues achievable by practicing zero tillage and minimal mechanical soil disturbance (Zarea, 2011). This study seeks to compare effects of tillage practices on WUEs and yields of drought tolerant bean varieties in Machakos County using three tillage systems CT, MT and ZT along with four varieties GLPX92, KATX56, KAT/B1 and KATRAM.

5.2 Description of study site

Katumani is a dryland Research Centre located in Machakos County on latitude 01° 35' S, longitude 37° 14' E, and an altitude of 1600 m above sea level (See section 3.1.1; Figure 3.1). It is located 8 km south-west of Machakos town and 80 km south-east of Nairobi. Katumani occupies a total area of 489 ha. Ecologically it falls under agro-climatic zone IV, which is described as medium to marginal (Jaetzold *et al.*, 2006). Rainfall is bimodal with annual mean rainfall as 711mm whilst the average seasonal rainfall is 301mm for the long rains (March-May) and 283mm for the short rains (October-December). However, the short rains tend to be more reliable for crop production than the long rains (Kwena *et al*., 2017; Recha *et al.*, 2012). Temperature range between 17 and 24°C (Jaetzold *et al*., 2006). The mean potential evaporation is in the range of 1820 to 1840 mm per year (Karuma *et al.*, 2014).

However, like other areas of the semi-arid eastern Kenya, rainfall occurs in events of unpredictable intensity, with coefficients of variation in seasonal rainfall often exceeding 50% (Recha *et al.*, 2012; Keating *et al*., 2010). Therefore, the timing and relative lengths of each growing period vary substantially such that any delays in planting, particularly at the start of the wet season bring risks of significant losses in yield almost proportional to the time delay (Keating *et al.*, 1992 ; Jewell *et al.,* 1994; Kinama *et al*., 2007). The first rains occur from March to May with a peak in April. These are referred to as the long rains. The second season falls in October to December with a peak in November and is also known as the short rains.

Predominantly, Katumani is covered by Lixisols derived from granitoid gneiss of the Basement System Complex. Unlike other areas of semi-arid Eastern Kenya, soils in Katumani are deep to very deep, well drained, dark red to reddish brown, weakly structured and friable, with sandy and sandy loam near the surface (Karuma *et al.*, 2014). In semi-arid Eastern Kenya, soils are faced with fertility and slightly acidic in reaction. The cation exchange capacity (CEC) of these soils is generally low to very low (e.g. 7.8 cmol kg^{-1}), (Itabari *et al.*, 2013; Composition *et al*., 2016). The soils are often deep and well structured, allowing deep penetration of plant roots and a moderately good capacity to hold available water (Simpjol & Luhllfwa, 1996). The soil also exhibit high erodibility, surface capping under raindrop impact resulting in poor infiltration of rain water hence high runoff, serious erosion, and lose of nutrients on many of the steeper cropland sites (Simpjol & Luhllfwa, 1996).

Plate 2. Site selection for experimental work (2016)

The landscapes consist of flat to hilly elevations with relief variation of 10-20m. The slopes are straight with gradient range between 2% and 20% (Kutu, FR, 2012). The main agricultural production enterprise in the surrounding area is mixed crop-livestock production systems with varying degrees of integration. Main crops are maize, beans, pigeon pea, cowpea and sorghum.

5.2.1 Experimental design, layout and agronomic activities

Plate 3: Site preparation for planting

The main plot contained three tillage practices in a randomized complete block design (RCBD) and replicated four times while the sub-plots contain 4 drought-tolerant bean varieties. Each sub-plots containing the tillage practices (CT, MT and ZT), were separated by 1 m path way and 0.75 m row and each block was separated by 3 m × 2 m horizontal and vertical path ways respectively and plot numbers were 48. The plots sizes were 2 m × 8 m respectively. The experiment comprised of 12 treatments in a 4 × 3 Split plot RCBD replicated four times. They included four drought-tolerant common bean varieties (GLPX 92, KATB1, KATX 56 and KATRAM) and three tillage systems; conventional tillage (CT), minimum tillage (MT) and zero tillage (ZT) combined as follows:

Table 5.1: Varieties arrangement in the three tillage practices in the experimental area

Varieties	Tillage
GLPX 92	Conventional Tillage
GLPX 92	Minimum Tillage
GLPX 92	Zero Tillage
KATB1	Conventional Tillage
KATB1	Minimum Tillage
KATB1	Zero Tillage
KATX56	Conventional Tillage
KATX56	Minimum Tillage
KATX56	Zero Tillage
KATRAM	Conventional Tillage
KATRAM	Minimum Tillage
KATRAM	Zero Tillage

The varieties were selected by breeders first then farmers through a survey conducted in the study area through assistance of local leaders and extension officers. In the conventional tillage system, the entire field was ploughed before planting while in minimum tillage (MT), the entire field was not ploughed but only the rows where seeds were planted were ploughed.

Plate 4: Crop view during SR season

In the No-till (NT), holes were dug only in areas were seeds were planted thereby maintaining soil cover in both MT and NT while CT was bare. Common beans were planted at a spacing of 50 cm between and 10 cm within rows. Three seeds planted per hole but later thinned to two after germination to reduce competition for nutrients. In the conventional tillage, the land was ploughed using chisel mounted on oxen a month before planting. In these plots, 48 plastic pipe access tubes were installed firmly in the soil using an auger to a depth of 1 m or whichever shallower for the purpose of moisture reading. Additionally, two plastic pipe access tubes were installed outside the experimental plots for neutron probe calibration purposes making the total access tubes to 50 pieces. The field slope was virtually even thereby making erosion negligible.

5.2.2 Data collection

Plate 5: Initial soil sampling.

The initial soil characterization was done by sampling soil from a depth of 0 -30 cm from various points using an auger and a composite of the soil was used to carry out physical and chemical analysis to determine the texture and nutrient status of soil in the study area. Soil texture was determined by the hydrometer method and Textural classes were read directly from USDA textural triangle (Bouyoucos 1962). Soil bulk density was done using the method described by (Brown & Wherrett, 2014). Soil pH was measured with a glass electrode pH meter on 1: 2.5 ($^{w}/_{v}$) suspension of soil in water, and on 0.01M $CaCl_2$ solution, in all cases after shaking for 30 minutes (Okalebo *et al.,* 2002). Electrical Conductivity (EC) was measured in a 1:2.5 Soil water suspensions using an EC-meter. Soil organic carbon **(%C)** was estimated by the Walkley-Black method (Schumacher, 2002). Total nitrogen (%N) and available P were estimated by the semi-micro Kjedhal and Olsen method (Elrashidi, 2010). Total cations were analyzed using Mehlich method Taylor *et al*. (2007) and determined using Atomic Absorption Spectrophotometer (Bulk Scientific model 210.

Rainfall and air temperature were collected from the nearby meteorological station within Katumani research station for determination of ETo for the season. Total available water content (TAWC) ($m^{-3}.m^{-3}$) was taken at planting, vegetative, flowering and podding stages referred to as, at planting and Days after planting (DAP) using Neutron probe 503DR Hydro probe. This was calibrated using the gravimetric water content (g/100 g soil) by plotting a graph of neutron counts against gravimetric water content. A line of best fit was developed with $y = mx + c$ equation. Where y - gravimetric water content, m - gradient, x - is the neutron counts and C is the y interception in this case zero interception. Therefore, all the neutron probe readings were converted into gravimetric readings by multiplying with m gradient of the line of best fit. Finally, Gravimetric water content was converted to volumetric water content using soil bulk density as outlined in Chapter three (Equation 3.1) (Tobergte and Curtis, 2013).

The soil moisture retention was determined from soil samples collected in the field from the Katumani Research station and analyzed at the University of Nairobi Soil Science

Laboratory using various water retention points from 0 – 15 bar (pF 0 to 4.2) before planting to determine the saturation, field capacity, wilting point, limit of readily available water and permanent wilting point of the soil in the study area to serve as a guide for irrigation scheduling and early warning signs to farm managers and farmers.

Above-ground biomass was collected after harvesting at the maturity stage of the crop from the inner rows after discarding the outer two rows from all four sizes of each experimental plot. Pods were extracted and the biomass was weighed per plot. Grain yield was collected at the maturity stage of the crop after harvesting and sun-dried at 13% commercial value and weighed. Harvested grain yield was converted to per hectare basis using Equation 3.1 while WUE was calculated using Equation 3.3 as outlined in Chapter three.

5.3 Statistical analysis

Data on bean yield and WUE were subjected to a two-way analysis of variance (ANOVA) using Genstat 14th edition software statistical package at and significance determined at $P \leq 0.05$. Mean separation was carried out using Duncan Multiple Range Test (DMRT) based on treatment size. The experiment model was a 4 × 3 split-plot randomized complete block design (RCBD) (Model) where main plot factors were the tillage practices and sub-plots factors were the varieties.

5.4 Results and discussions

5.4.1 Soil characteristics of the study area during the SR and LR

In both cropping seasons (SR and LR), the initial soil characteristic suggest that the soil of the study area had an acidic pH and low organic carbon to nitrogen ratio and had phosphorus in low to medium quantities (Table 5.2). This indicated the characteristic of luvisols in the study area (Karuku & Mochoge, 2016). However, rating for phosphorus levels in the study area range from 20 - 200 as medium to very high, while 0 - 20 as low to very low (Gicheru and Ita, 1987). The texture of the soil is sandy clay loam with a slow hydraulic conductivity and a high bulk density indicating compaction either due to previous tillage practices or by grazing animals' based on the mixed cropping system and human induced activities. Initial soil moisture content for both seasons ranged from 1.21 to 1.83 m^3m^{-3} and was as a result of rainfall before planting (Table 5.2).

These results implies that the initial moisture content for the SR season was higher than that of the LR due to precipitation received during the onset of the cropping seasons. In this experiment, it was prudent to evaluate the soil nutrient status to understand other factors hampering WUE and grain yield given the fact that the two work together to enhance agricultural productivity. As a result of the wider scope of agricultural WUE, the use of agronomic and biological solution must be considered on a broader level (Deng *et al*., 2006). However, in arid and semi-arid areas, nitrogen plays a vital role in improving agriculture WUE while phosphorus assist plants in deep extraction of water from soil layers (Zhong and Shangguan, 2014). From the initials soil characteristic (Table 5.2), di-ammonium phosphate (DAP) 80 kg/ha and rhizobium inoculant (USDA 2667) at the rate of 150g/15 kg legume seeds, were used as soil amendments to improve the soil nutrient status before planting during both seasons (SR and LR). During the drought period (SR), GLPX92 had the highest WUE under CT system while during favorable season (LR), KAT/B1 had the highest WUE under (NT) followed by KATRAM. These results, agrees with Sharma, Molden, and Cook, (2015) and Turner, (2004) and Wang *et al.* (2016), that increased use of chemical fertilizer in dryland farming double grain yields and WUE.

Table 5.2: Initial soil characteristics at onset of the experiment

Parameters	Units	Short rain	Long rain
pH	v/v (H_2O)	5.21	5.06
OC	%	1.11	1.16
N	%	0.08	0.12
P	Ppm	18.43	23.4
K	Cmol/kg	1.2	1.7
Ca	Cmol/kg	5.88	4
Mg	Cmol/kg	1.69	1
CEC	Cmol/kg	12.24	12
Mn	Ppm	51.5	65.1
Fe	Ppm	64.14	50.58
Zn	Ppm	11.95	12.5
Al	Cmol/kg	1.98	2
Ksat	$cm.hr^{-1}$	1.18	1.18
sand, silt, clay (sandy clay loam)	%	69, 5, 26	69,5, 26
Bulk density	$g.cm^{-3}$	1.4	1.4
Soil moisture content at planting	$m^3. m^{-3}$	1.83	1.21

5.4.2 Rainfall and air temperature during both SR and LR

The mean monthly rainfall and temperature during the experimental period (October, 2016 to June, 2017) are given in Figure 5.1. The cumulative rainfall for both the short and long rains was 164 mm and 380 mm which was below and above average respectively. During the SR, October and January had little or no rain and the peak of the rainfall during the short rain season was in November and this season experience erratic and sparsely distributed rainfall with average air temperature of 24 $^{\circ}$C (Figure 5.1). However, during the LR, rainfall peak was in April and temperature rise was 25 $^{\circ}$C and in March, the peak of the SR season experience little rainfall than the peak of the LR. The months of October and June were both the harvesting stages of the two seasons (SR and LR). Due to intense drought, actual planting took place in November due to insufficient rainfall to improve germination. On the contrary, planting for the LR took place in March due to sufficient amount of rainfall received which was adequate for planting and seeds germination in these highland areas. Moreover, many agricultural systems in semi-arid tropics where soil evaporation, runoff and soil losses are important (Kinama *et al*., 2005); Kinama *et al*., 2007) needs serious attention as it relates to crop production and food security for rural household dwellers. The rainfall of the study area during both cropping seasons (SR and LR) had a lot of variations due to seasonal effects cause by climate change and drought. Recha *et al.* (2012) reported that increasing temperature and low rainfall couple with poor soil fertility impact negatively on productivity of various crops. The average temperature for the SR 22 °C and for the LR was 23°C indicating that temperature was high and rainfall was insufficient for production during the SR while temperature for the LR was high with considerable amount of rain for production but not all this rainfall went to production due to higher evaporation and high rate of transpiration.

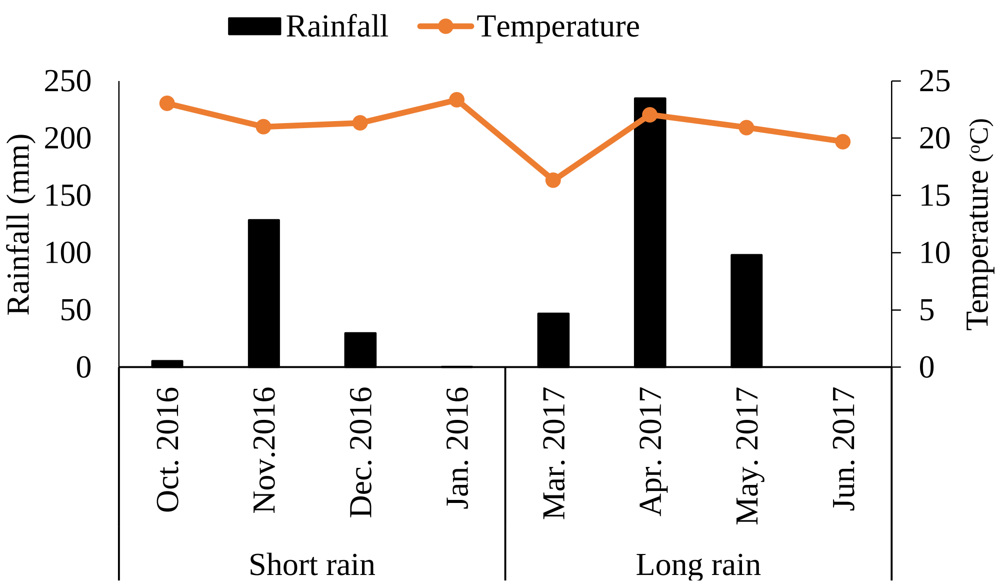


Figure 5.1: Distribution of rainfall and air temperature during the short and long rains.

Although evaporation and transpiration were not measured during this study, and because these have been taken care of by other researchers, this study thought it was prudent to use ETo to measure WUE (Kinama *et al*., 2005). Rainfall distribution as seen in Figure 5.1 could have greatly affected yield. The low and sparsely distributed precipitation during the SR in November 2016 and low rainfall during the LR at the onset of planting in March 2017 with peak in April. These events of rainfall portray that during the SR crops experience moisture stress during the flowering stage hence causing abscission of more flowers before entering the podding stage which as a result contributed to low yield with drought exacerbating the problem (Figure 5.3 and 5.4). In addition, rainfall for the LR was favorable though similar trend experienced during the SR at flowering was also experienced during the LR but was short lived hence yield was not affected as is seen in Figure 5.3 and 5.4.

Rainfall and temperature of the study area falls in line with "Weather forecast for Semenyih," (2013) where rainfall and temperatures were observed as normal, abnormal and warmest temperatures respectively. This could be the prevailing effect of low crop production in ASALs coupled with low soil moisture content and infertility during both SR and LR seasons. Gornall *et al*. (2010) argues that these changes in climate are expected to have differential impacts on agricultural productivity, food security across spatial and temporal scale. These erratic variability of rainfall experienced during the cropping season which is as a result of climatic effect caused by drought, is expected to have detrimental effects to agricultural livelihood in the tropic especially in Africa (Gornall *et al*., 2010).

5.6.3. Soil moisture variations under the two cropping seasons (SR and LR)

Soil moisture content varied significantly between depth and season ($P<0.001$) but not between tillage systems ($P = 0.052$). However, during the SR seasons, soil moisture increased with depth in the upper 60 cm and decreased in the lower 80 cm depth while soil moisture decrease in the upper 60 cm depth and increase in the lower 80 cm depth during the LR season. The interaction between tillage practices × depth was not significant ($P = 0.923$), but significant interactions was observed among tillage systems × seasons × depth × season ($P<0.001$, Table 5.3). However, interactions between tillage systems × depth × season was not significant (*P* = 0.818, Table 5.3). Soil moisture content was higher during the LR than the SR (Table 5.3). This could probably be as a result of the negative impact of climate change effects like drought, temperature rise and decrease in rainfall that is so severe in hot and dry area. Moreover, during the SR cropping season 2016, the study area experienced induced drought with erratic rainfall with mean precipitation of 164 mm being lower than the expected 283 mm and was sparsely distributed. Other studies reported air temperature ranging from 26 $^{\circ}$C to 14.23 $^{\circ}$C and 380 mm rainfall, 26 $^{\circ}$C to 14.3 $^{\circ}$C in temperature for the LR, and that average rainfall for both long and short rains range between 283 mm and 301 mm respectively (Jaetzold *et al*., 2006).

The results agreed with Keating *et al*. (1992) and Recha *et al*. (2012) who reported that rainfall events in the semi-arid eastern Kenya is unpredictable, with coefficient of variation in seasonal rainfall often exceeding 50%.

Soil moisture increased and decreased with depth during the SR cropping season in the upper 60 cm to the lower 80 cm (Table 5.3). During the long rain cropping season, soil moisture decreased in the upper 60 cm but increased in the lower 80 cm depth (Table 5.3). This could be as a result of the soil structure and texture that is well drained, deep to very deep and sandy to sandy clay loam Kwena *et al.*, (2017); Shittu *et al.*, (2017) or could probably be due to effect of tillage or rate of soil evaporation. However, soil moisture variation in the soil of the study area is attributed to the tillage systems and the seasons whilst soil moisture variation in the various depth of the soil is depicted by the seasons and the amount of rainfall received as well as the rate of evaporation due to temperature penetrating the soil surface and back to the atmosphere. Kinama (2015) argued that moisture reading at the top 30 cm of soil is underestimated as neutrons escape into the atmosphere and are not detected by neutron probe. This could be the reason probe reading during the SR which was marked by events of dryness cause by drought was difficult due to like of moisture in the upper soil layers.

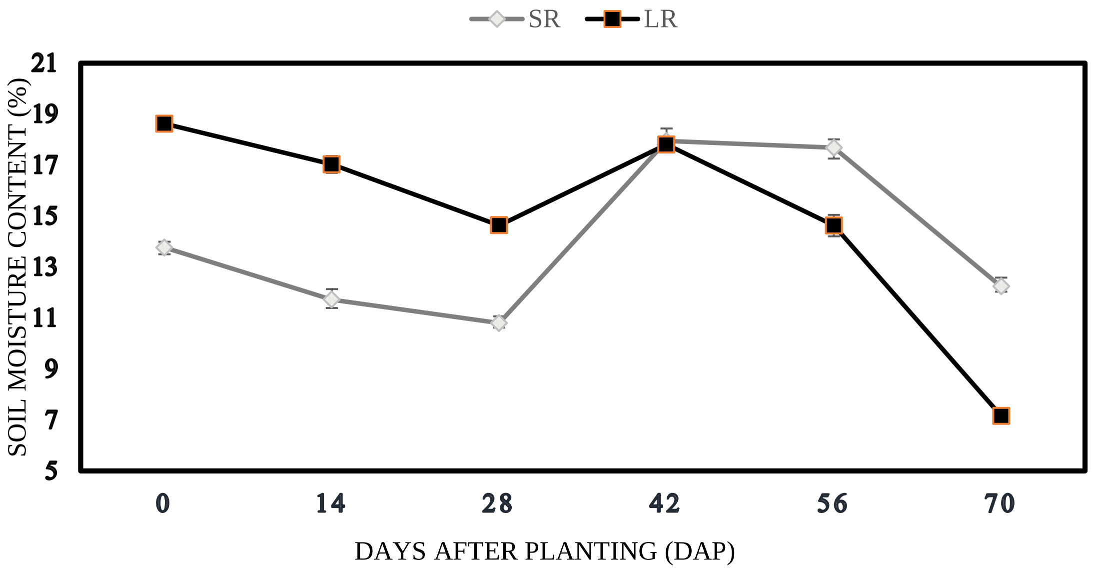
Table 5.3: Soil moisture content at various depths under the tillage systems during the two cropping season

Tillage system	Soil depth (cm)	Cropping seasons	
		Short rains	Long rains
Conventional tillage	20	10.0 ± 0.57	14.7 ± 0.84
	40	14.4 ± 0.47	15.4 ± 0.58
	60	15.0 ± 0.44	15.2 ± 0.46
	80	13.9 ± 0.53	15.6 ± 0.46
Minimum tillage	20	11.5 ± 0.67	14.1 ± 0.75
	40	15.9 ± 0.53	15.0 ± 0.44
	60	16.4 ± 0.53	14.8 ± 0.40
	80	16.3 ± 0.82	15.0 ± 0.43
Zero tillage	20	11.0 ± 0.49	14.4 ± 0.78
	40	15.2 ± 0.43	15.1 ± 0.47
	60	15.1 ± 0.48	15.2 ± 0.44
	80	13.7 ± 0.46	15.4 ± 0.46

Note: Values are means ± SE (standard errors).

5.4.4 Effect of tillage on soil moisture content in the short and long rains

Soil moisture content was high during the onset of the SR as compared to LR (Figure 5.2), and decreased towards the flowering stage (28 DAP) days after planting and later increased to podding stage (42 DAP) and decreased towards harvesting stage (70 DAP). Moisture content intercepted at 42 DAP (podding) and increase at 56 DAP (maturity) with the SR and decreased at 56 DAP (maturity) with the LR and finally decreased at 70 DAP (harvest) with both (LR and SR) season. Moisture content in the growth stages of crop is very important to yields and WUE of crops. Results of the study showed variations in soil moisture content during various phenological stages. This could be as a result of erratic rainfall variability experienced during both seasons the increased in temperatures. However, varieties did not influence soil moisture content at the various growth stages but tillage influenced moisture content at the various stages of crop growth. This could be as a result of the level disturbances exerted on the soil during seed beds preparations. In the study area, rainfall drop from 283 mm to 164 mm for the SR below the average rainfall of 283 mm which is low for bean production while the LR was above average from 301 mm to 380 mm. However, yield losses associated with drought at different crop growth stages of plant development have been looked at by many other studies (Farooq *et al.*, 2012; Aslam *et al*., 2015). Kinama *et al*. (2005) reported that evaporation can be quite high > 40% of total rainfall. Runoff from rainfall can reach 10% of total rainfall (Kinama *et al.*, 2007; Taylor *et al.*, 2007). Moreover, deep percolation in ASALS are negligible (Kinama *et al.,* 2007).



Note: 0 = day of planting, 14 = vegetative stage, 28 = flowering stage, 42 = podding, 56 = maturity stage and 70 = harvesting

Figure 5.2: Soil moisture content from planting to seventy days of plant growth in short and long rains (SR and LR)

There was a decrease and increase over time in soil moisture at different phenological stages after planting during the long and short rains (Figure 5.2). The trend in soil moisture content in the soil profile could be as a result of rainfall, tillage practices and soil pores, crop water uptake, transpiration, evaporation due to environmental demand and deep percolation (Table 5.2) (Karuma *et al.,* 2014). These variations occurred as a result of the tillage systems and the temperature rate hitting and penetrating the soil profile (Table 5.2 and Figure 5.2). Minimum tillage (MT) had high soil moisture content due to reduced soil disturbance and intact soil micro pores which supported moisture retention. This practice also retained residues above the soil which served as mulch that reduced soil moisture evaporation. This process was also observed with No-till (NT) and Conventional tillage (CT) the least. This could be due to the topography and undisturbed porosity but on the contrary, the impact of rain droplets on the soil surface, and crusting Shittu *et al.* (2017) could be the cause of increased erosion and low moisture infiltration NT system. Negassa *et al*. (2012) showed that crown root initiation and anthesis are the two stages in which losses from drought stress can be more critical in wheat.

Moreover, Vaghasia *et al*. (2010) reported that increased soil moisture supply will lead to increase in water use. This could be the cause of the variation in biomass and grain yields during the LR season as a result of higher rainfall compare to the SR season. Çakir (2004) reported that between two moisture stress treatment, stress given at flowering stage cause reduction in pod yield while reduction in grain due to moisture stress imposed at pod development stage. During this study, similar trend was observed at various phenological stages especially during flowering and podding stages for both season (SR and LR) rains (Figure 5.2). During these stages, crops experience moisture stress before reaching maturity which may have contributed to the low yield. This could probably be one of the many contributing factors to low production of common bean in many semi-arid areas of Kenya as a result of moisture stress caused by climatic effects like drought.

5.4.5 Effect of tillage practices on grain yield

Generally, tillage had no significant effect on grain yields (P=0.651, Figure 5.3), but there was significant effects found between the interactions of tillage × season (P = 0.037, Figure 5.3) and could be as a result of climatic factors like drought and the type of tillage system that conserve moisture for crop and avail to plant for proper growth and productivity. Seasons also had significant effect on grain yield ($P<0.001$, Figure 5.3). However, interaction between tillage and varieties had no significant effects on grain yields (P = 0.382). A trend was observed among varieties with GLPX92 recording higher yield during the SR (Figure 5.3). A trend was also observed among the tillage systems with NT and CT and recording higher yields compared to MT. However the differences were not significant. This concurs with Shittu *et al*. (2017), that inadequate moisture coupled with transpiration decrease plant growth rate and the final grain yield and this can also be in the reversed. Interestingly, season and the interaction between tillage and season had significant effect on grain yield. This could be attributed to the effect of soil properties such as low carbon to nitrogen ratio, low to medium P levels acidity of the soil couple with climatic factors like drought, erratic rainfall and increase temperature.

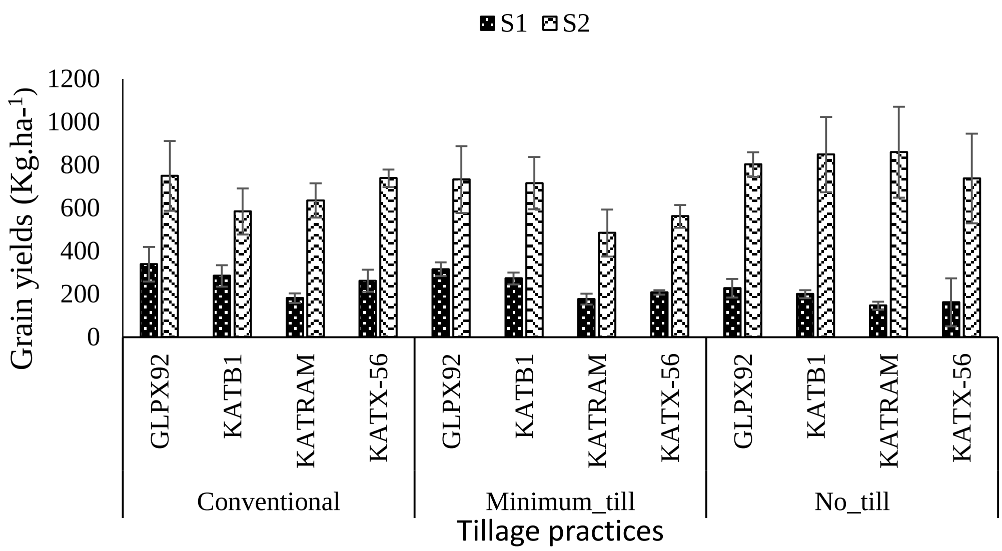


Figure 5.3: Effect of tillage practices on grain yield.

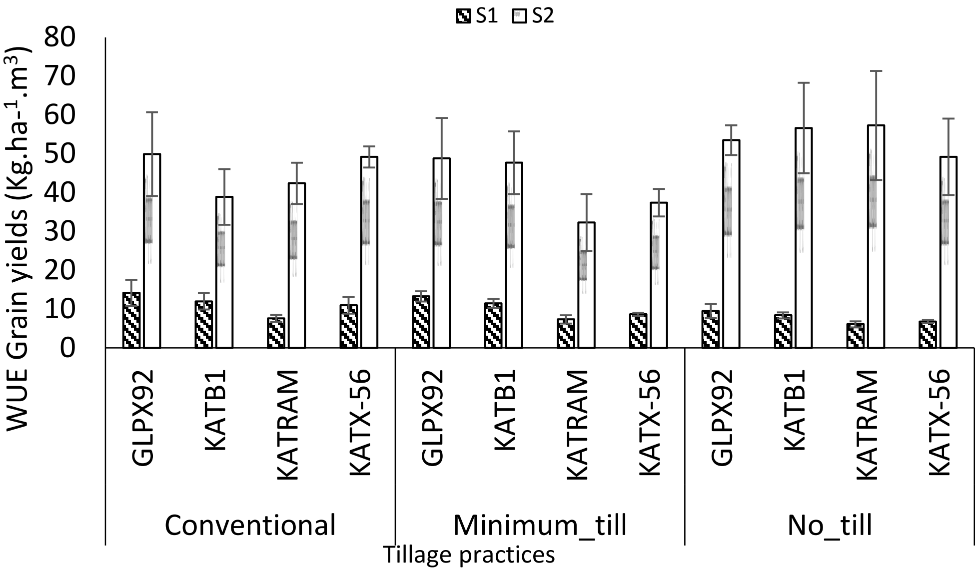
Additionally the study area, like other semi-arid areas was severely hit by drought during the SR season 2016, which led to crop failures and low grain yield. This was due to low average rainfall of the study being 184 mm for the SR below the minimum average of 283 mm whereas the LR season was reliable exceeding the minimum average of 301mm to 380 mm of rainfall. However, tillage and varieties had no effect on grain yield but there were some variations observed among the varieties and moisture content which was not significant decreasing with GLPX92, KATB1, KATX56 and KATRAM. However, GLPX92 performed better in terms of higher grain yield in both season in all tillage systems followed by KATB1, KATX56 and KATRAM but the yields weren't significant. Similarly, the same order was observed in tillage practices (NT, CT and MT). Moreover, during the LR season in 2017, soil moisture content was high as a result of favorable rainfall giving higher grain yield.

5.4.6 Effect of tillage systems on WUE grain yield

Tillage and varieties, and their interaction had no effect on WUE grain yield (P = 0.582, 0.181 and 0.439 respectively). However, season alone had significant effect on WUE of grain yield ($P<0.001$) but had no effect when interacting with tillage (P = 0.055). The interactions between varieties and season was not significant on grain yield WUE (P = 0.994) while the interaction among tillage, varieties and season had no significant effects on grain yields WUE (P = 0.867). This could be attributed to the two broad variation experienced during the two cropping season (SR and LR) base on the semi-arid nature of the study area (Wang *et al.*, 2016). Though tillage and varieties had no effect on WUE of grain yield, but during the SR season marked by extreme drought, it was observed that crops grown under CT and MT performed better than NT though not significant. From the results obtained, the LR in 2017, performed better on WUE grain yield under conservation tillage system with favorable climatic condition and good soil moisture availability.

Moreover, according to Busari *et al*. (2015), tillage impact on yield is related to its effects on root growth, water and nutrient use efficiencies and most importantly agronomic yield. Moreover, according to Powlson *et al.* (2014), climate adaptation benefits of NT can be significant. But from this studies it was observed that this depends on the region, soil properties and soil structure. More besides, the report also stated that wheat grown during Kazakhstan's 2012 drought and high temperature, under NT practices were more resilient, leading to higher yield over conventional.

Results emanating from this study show that during the SR season yields were lower and NT performed least while CT and MT performed better during the drought period though statistically insignificant. This could be associated to lack of soil moisture, hard bulk density, drought and increased temperatures. This study concurs with Obalum *et al.* (2011) that tillage had no influence on the total WUE of crop during the both season. This could be attributed to the difficulties to determine crop transpiration accurately under field conditions (Mwehia, 2015). However, most researchers are using evapotranspiration (ET) to describe WUE though transpiration, erosion and evaporation has being taken care of (Kinama et al., 2005). This study did not measure these variables due to lack of equipment and financial constraints and so the best option was to use ETo where WUE was measure by expressing biomass or grain yields over ET common crop.



Note: S1- season one (SR), S2- season two (LR)

Figure 5.4: Effect of tillage practices on WUE of grain yield

5.4.7 Effect of tillage systems and varieties on biomass WUE

Tillage and varieties effects on WUE of biomass yields were not significant (*P* = 0.320, 0.604 Table 5.4) respectively. The interactions between tillage × varieties had no significant effects on biomass WUE (*P* = 0.260) however, observed was significant effect of season on biomass WUE (P < 0.001) and interactions between tillage and season had significant effect on biomass WUE (*P* = 0.010) but interaction between varieties × season had no significant effect on biomass WUE (P = 0.985, Table 5.4) while the interaction between tillage × varieties × season had no significant effect on biomass WUE (P = 0.756, Table 5.4). Similar trend was observed with tillage having no significant effect on biomass yields (P = 0.336, Table 5.4) while varieties and the interactions between tillage × varieties had no effects on biomass yields respectively (P = 0.463, 0.247) but observed was season and the interaction between tillage × season having significant effects on biomass yields (P < 0.001, 0.009, Table 5.4) respectively. Moreover, the interactions between varieties × season had no significant effects on biomass yields at (P = 0.988, Table 5.4) and no significant effects of interactions between tillage × varieties × season was observed on biomass yields (P = 0.819, Table 5.4). This could probably be as a result of climatic conditions, due to moisture stress or soil moisture availability. However, there was an effect of season observed on biomass WUE during the two cropping season (SR and LR) which is either as a result of increased temperature, higher evaporation rate from the soil Figure 5.1.

Moreover, observed was varietal variation on WUE existing within the common bean varieties grown in the experimental plots under the two season (SR and LR) using three tillage systems CT, MT and NT) respectively. This variation could be utilized in selecting varieties for breeding suited to field sites of varying water availability (Of *et al*., 1996). The results of this study disagrees with Of *et al.* (1996) that varieties which may have higher WUE under water stress may not be the most superior one in terms of WUE under well-watered conditions. However, in the two cropping seasons, GLPX92 had the highest yield under moisture stress during the SR drought and also under favorable season of the LR with in the various tillage practices.

Moreover, there was no interaction found between varieties and season on biomass WUE. This is because total dry weight of biomass can be attributed to the balance between photosynthesis and respiration Of *et al.* (1996) which indicate that a lower respiration would increase the total biomass accumulated per unit of water transpired. However, varieties and tillage and season had no significant interaction on biomass WUE. Results from this study agrees with Of *et al*. (1996) that WUE be a promising selection criterion when breeding for drought tolerant, in combination with conservation tillage system which promote soil health and viable soil moisture storage to enhance growth of crops in the semi-arid areas.

Table 5.4: Effect of tillage practices on biomass yield and water use efficiency among different common bean varieties

		Short rains		Long rains	
Type of Tillage	Varieties	Biomass	WUE	Biomass	WUE
Conventional	GLPX92	654 ± 280.2	27.5 ±11.7	1392 ± 380.7	92.8 ± 25.4
	KATB1	569 ± 237.7	23.9 ±10.0	1160 ± 371.7	77.3 ± 24.8
	KATRAM	535 ± 141.8	22.5 ± 6.0	1342 ± 323.0	89.5 ± 21.5
	KATX-56	604 ± 184.8	25.4 ± 7.8	1419 ± 240.1	94.6 ± 16.0
Minimum till	GLPX92	569 ± 100.5	23.9 ± 4.2	1283 ± 446.9	85.5 ± 29.8
	KATB1	577 ± 91.0	24.2 ± 3.8	1275 ± 374.3	85 ± 25.0
	KATRAM	450 ± 105.4	18.9 ± 4.4	944 ± 425.2	62.9 ± 28.3
	KATX-56	485 ± 62.2	20.4 ± 2.6	1123 ± 233.9	74.9 ± 15.6
No till	GLPX92	492 ±151.8	20.7± 6.4	1479 ± 248.2	98.6 ± 16.6
	KATB1	435 ± 127.7	18.3 ± 5.4	1744 ± 540.4	116.3 ± 36.0
	KATRAM	423 ±73.8	17.8 ± 3.1	1623 ± 481.2	108.2 ± 32.1
	KATX-56	462 ±33.2	19.4 ± 1.4	95.9 ± 28.1	95.9 ± 28.1

P-values, tillage (P = 0.320), varieties (P = 0.604), tillage and varieties (P = 0.260), season ((P < 0.001), tillage × season (P = 0.010), varieties × season (P = 0.985), tillage × varieties × season (P = 0.756), Biomass Yield × Tillage (P = 0.336), varieties (P = 0.463), tillage × varieties (P = 0.247*)*, season (P < 0.001*)*, tillage × season *(*P < 0.009) and varieties × season (P = 0.988).

5.4.8 Relationship among treatments, yields, WUE and soil moisture content

There was a strong correlation between biomass and grain yield (*R* = 0.98), and WUE of biomass and grain yield (*R* = 0.97) (Table 5.5). Similar relationship was observed between; WUE of grain yield and grain yield (*R* = 0.99), between biomass yield and WUE grain yield (*R* = 0.98), and WUE of biomass and WUE grain yield (*R* = 0.98) (Table 5.5). This implies that the effect of season on soil moisture will determine dry matter weight and grain yield under drought and favorable season as was express in yields during both seasons (SR and LR) Figure 5.3. However WUE cannot be measured in the absence of the two components (biomass and grain). Moreover, WUE from this study, was derived from both the biomass and grain yield express over the ET common crop. *Z*hang *et al.* (2016) reported that the decrease in WUE under alternative practices can be attributed to the corresponding decrease in the grain yield, in agreement with the strong positive relationships between the WUE and grain yield of the study result Table 5.5. Moreover, there was no relationship among seasonal moisture content, tillage systems, common bean varieties and biomass and grain yield to biomass yield WUE and grain yield WUE. However, the positive correlation between WUE and biomass and grain yields and harvest index at 70 DAP adds weights to the significance of WUE as a useful selection criterion in breeding and selection of cultivar for high performance under drought in semi-arid areas and the world at large.

Table 5.5: Correlation among tillage, common bean varieties, biomass and grain yield, WUE biomass and WUE grain yield and seasonal moisture content

	Tillage	Varieties	Grain yield	Biomass	WUE-B	WUE-G	SM
Tillage	-						
Varieties	-0.01	-					
Grain yield	0.04	0.01	-				
Biomass	0.04	0.01	0.98*	-			
WUE-B	0.05	0.01	0.97*	0.99*	-		
WUE-G	0.05	0.01	0.99*	0.98*	0.98*	-	
SM	-0.11	0.16	0.04	0.07	0.08	0.05	-

WUB-B- water use efficiency biomass, WUE-G – water use efficiency grain yield, SM – soil moisture

5.5 Conclusions and recommendations

The results evolving from this study indicate that soil conservation tillage systems are significant for yield of different drought tolerant common bean varieties and WUE in Machakos County, Eastern Kenya. This is from the backdrop that conservation tillage systems conserved higher moisture content and kept the soil micro and macro pores intact as well as soil structure while influencing soil moisture trend during the phenological stages. This is evident based on the results from the both season with NT having higher variation in grain yield than CT followed by MT though insignificant. Higher yield in CT is as a result of the loosening of the soil allowing for ease of roots penetration and easy infiltration of rain water. From other studies, many researchers argues that this practice is not sustainable in semi-arid areas in that it will further degrade the soil due to higher impact of raindrop on soil surface and increasing erodibility due to increased fragility of soil. However in the near future, soil compaction will occur and rain water infiltration will be hampered. Unlike conservation tillage systems will promote soil moisture storage and increased soil stability and reduce the level of radiation entering the soil and increasing grain yield and higher WUE. There is a need for further research to determine why GLPX92 exhibited such dominant characteristic in yields and WUE above KAT/B1, KATX56 and KATRAM during the both seasons (SR and LR).

Results emanating from this studies, recommend conservation tillage systems to be the best option for the cultivation of different drought tolerant common bean varieties in semi-arid areas like Machakos County due to the soil moisture conservation ability of said practices as compared to conventional tillage systems which is not a sustainable practice in such marginal areas. The studied varieties, GLPX92, KAT/B1, KATX56 and KATRAM are all drought-tolerant and may be used to reduce poverty and increase food security in semi-arid areas like Machakos County.

Finally, I would recommend the arguments of other researchers who argues that conventional tillage systems is unsustainable in that it further degrade the soil and reduce soil moisture content, increased soil erodibility, increased soil radiation and reduce grain yield and WUE.

CHAPTER SIX

Determination of the water use efficiency (WUE) of drought tolerant common bean varieties

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Abstract

In semi-arid regions, like Machakos, crops use only a small fraction of total rainfall received in many agricultural systems. An experiment was set up to evaluate initial soil characteristics, determine moisture retention using pF-curve as early warning for irrigation scheduling, determine moisture trends during phenological stages, determine water use efficiency (WUE) of grain and above ground biomass production of four selected bean varieties. The experiment was laid out in randomized complete block design with 4×3 Split-plot arrangement and replicated four times from 2016 to 2017 for two season. The treatments were conventional tillage, minimum tillage and zero tillage replicated four times. The bean varieties were GLPX92, KAT/B1, KATX56 and KATRAM replicated four time in a 4×3 Split-plot arrangement. Soil moisture was taken using neutron probe at different depths. From the results, GLPX92 had the highest WUE followed by KAT/B1, KATX56 and KATRAM the least performing. Tillage did not influenced biomass WUE (P = 0.320) neither did interaction between tillage × varieties influenced WUE biomass. Soil of the study area read field capacity as pF 2 to pF 2.5 and relative available water (RAW) at pF 3.7 or 5.0 bar and wilting point at pF 4.2 or 15.0 bar (Figure 1.1).

Keys words: Bean grain and biomass WUE, phonological stages, pF- curve and semi-arid.

6.1 Introduction

Common bean (*Phaseolus vulgaris* L.) in sub-Saharan Africa is a frontline crop in fighting hunger, malnutrition and poverty. The crop is a food secure and nutritious crop especially in this region (Namugwanya *et al.*, 2014). In Kenya, the greatest challenge is to grow enough food to feed the increasing population, which is increasing at 2.5% per annum (Mwehia, 2015). Katungi *et al*. (2011) argued that common bean is a leading legume in both production and consumption in Kenya. Namugwanya *et al*. (2014) estimated that the crop meet 50% of dietary protein requirement of household in SSA. Production of this crop has drop dramatically due to biotic and abiotic factors mostly in semi-arid areas of Kenya. However, soils of the study area had poor infiltration, surface capping, and ceiling with degraded land poor in major nutrients like N, P, and K.

Moreover, to mitigate unawareness of low moisture content in the soil, pF curve is used as an early warning sign to soil moisture retention characteristics which is basically dependent on soil structure, texture and the crop under cultivation (Alphen *et al*., 2000). Soil in the study area are difficult to till during cropping season due to extreme dryness and animals used to plough are very weak because of the lack of feed (Kinama *et al*., 2007). Additionally, farmers without Ox and implements have to rent from their colleagues to plough hence causing delay and low yields. According to Kwena *et al*. (2017), any delays in planting, particularly at the start of the wet season bring risks of significant yield losses almost proportional to the time delay. In Tanzania, Bucheyeki and Mmbaga, (2013) attributed the low yield of the crop to the use of unimproved varieties with low yield potential.

This study aimed at evaluating the water use efficiency (WUE) of four varieties of common bean (GLPX92, KAT/B1, KATRAM and KATX56) to bridge the production gap in the study area faced by moisture challenge due to climatic variability caused by drought hence crop failures in many semi-arid areas of Kenya. Koech *et al*. (2015), reported that under water deficient environments, WUE is a critical consideration of plant productivity hence, for semi-arid the study area, WUE will be refer to as the yields divided by the ET crop. However, other researchers like Sinclair *et al*. (1984) referred to WUE as the amount of dry matter per unit of water lost in both transpiration and evaporation. Under field condition, crop transpiration is difficult to determine (Mwehia, 2015). However, other researchers have measured transpiration by separating E from ETo since not all water received from rainfall goes to production (Kinama *et al*., 2005).

Also, most of the water received is transpired by crop during greater atmospheric demand, soil evaporation, runoff Kinama *et al*. (2007) and deep percolation. WUE was estimated using Transpiration (T) obtained from soil water balance in semi-arid Kenya. Soil evaporation was estimated at over 40% of the total rainfall and runoff as 10% of the total rainfall in monocrop maize under control treatment maize plot (Kinama *et al*., 2005). However, Rost *et al*. (2009) explained that the main focus of arid and semi-arid areas on crop production is the efficiency with which water is used. Therefore, this study used ETo to determine the effect of drought tolerant common bean varieties on WUE, grain and biomass yields as a way of enhancing farmers' capacity in increasing yield with the available water using crops that are tolerant to drought under rainfed agriculture especially in arid and semi-arid areas of Kenya.

6.2 Site description

Katumani dryland Research Centre is located in Machakos County at latitude 01° 35' S, longitude 37° 14' E, and an altitude 1600 m above sea level and 80 km southeast of Nairobi. Rainfall is bimodal with annual mean rainfall as 711mm whilst the average seasonal rainfall is 301 mm for the long rains (March-May) and 283 mm for the short rains (October-

December). The short rains tend to be more reliable for crop production than the long rains (Kwena *et al*., 2017). Temperature range between 17 and 24°C (Jaetzold *et al.*, 2006). The mean potential evaporation is in the range of 1820 mm to 1840 mm per year (Gicheru and Ita, 1987). However, the semi-arid eastern Kenya, rainfalls are unpredictable with coefficients of variation in seasonal rainfall often exceeding 50% (Kwena *et al.*, 2017).

Katumani is covered by Lixisols soils derived from granitoid gneiss of the Basement System Complex. They are deep to very deep, well drained, dark red to reddish brown, weakly structured and friable, with sandy and sandy loam near the surface (Gicheru and Ita, 1987). In semi-arid Eastern Kenya, soils are faced with fertility and slightly acidic in reaction. The cation exchange capacity (CEC) of these soils is generally low to very low (e.g. 7.8 cmol kg^{-1}) (Composition *et al.*, 2016; Itabari *et al.*, 2013).The soil also exhibits high erodibility, surface capping under raindrop impact resulting in poor infiltration of rain water hence high runoff, serious erosion, and lose of nutrients on many of the steeper cropland sites (Simpjol and Luhllfwa, 1996). The soil characteristics of the study site are given in Chapter five section 5.4. The landscape of Katumani consists of flat to hilly elevations with a relief variation of 10 - 20 m. The slopes are straight to gradient range between 2% and 20% (Kutu, 2012). The tillage systems used in the study area are conventional and conservation tillage systems that have being approved by Ministry of Agriculture and other relevant authorities that have stake in land conservation issues in semi-arid areas (Recha et al., 2012).

6.2.1 Experimental design and layout

The experiment comprised of 12 treatments in a 4×3 split plot Randomized complete block design (RCBD) and replicated four times. The sub-plots included four drought tolerant common bean varieties; KAT/B1, KATX56, GLPX92 and KATRAM. The major plots comprised of three tillage systems: conventional tillage Ox-drift (CT), minimum tillage hand hoe (MT) and zero tillage (ZT) arranged as in (Table 1) Chapter Five. The varieties were selected by farmers in a survey conducted in the three locations; Kyamuluu, Mwania and Kaathi villages through the assistance of local leaders and extension liaison officers from Kenya Agricultural and Livestock Research Organization (KALRO), Katumani. However, the basis of selection according to the farmers was due to High WUE and grain yield and high selling rate.

The experimental plots measured 2 m × 8 m. Common beans were planted at a spacing of 50 cm between and 10cm within rows. Three seeds were planted per hole but were later thinned to two after germination to reduce competition for nutrients and increase proper growth within varieties. In the conventional tillage, the land was plowed using a chisel and tow oxen to pull the draft to till the soil a month before commencing of planting seeds in the field. The treatments were arranged in a 4 × 3 split-plot arrangement in Randomized complete block design (RCBD). The land size of the experimental area was 61 m × 18 m. Plot size was 2 m × 8 m and rows between plots were 0.75 m. The sub-plots were separated by a 1m path-way and the four blocks horizontally and vertically were separated by 3 m × 2 m path-ways respectively. There was a total sum of 48 plots with 48 access tubes for moisture reading drilled with auger, one in each plot excluding the 2 access tubes drilled out of the experiment plots for calibration of the 503 DR Hydro probe. Weeding in the experimental plots and site area were done with hand hoe and spread on the soil surface beneath the crop to reduce soil moisture evaporation, thereby giving rise to soil moisture conservation for crop use.

6.3 Data collection

6.3.1. Soil field capacity and permanent wilting point

These were determined from soil samples collected in the field from the Katumani Research station using core rings sealed with lid and taken to Kenya Agriculture Research and livestock Organization Laboratory Westland branch where the soil was analyzed at pF 0, 2.0, 2.3, 2.5, 3.7 and 4.2 pressures (N/m^2) to determine the retention of soil moisture ($m^{-3}.m^{-3}$) by pressure plate method (Blake & Hartge, 1986).

6.3.2 Total available water content (TAWC) ($m^{-3}.m^{-3}$)

This was taken bi-weekly for three hours a day at every moisture reading during the phonological stages of plant using a neutron probe (503DR Hydro probe) lowered down into the access tubes installed in every sampling units in the experimental area. A total of 50 tubes were installed, one each in every plot. A total of 48 tubes were used for the experimental units while two tubes were used for calibration at every sampling time of which probe is lowered down the tubes to collect moisture readings from 20 cm up to 80 cm depth.

6.3.3 Calibration of the neutron probe

The probe was calibrated using the gravimetric water content (g/100 g soil) by plotting a graph of the ratio of neutron counts and standard count against gravimetric water content. A line of best fit was developed with $y = mx + c$ equation. Where y - gravimetric water content, m - gradient, x - is the neutron counts and C is the y interception in this case zero interception. All the neutron probe readings were converted into gravimetric readings by multiplying with m gradient of the line of best fit. Gravimetric soil water content was converted to volumetric water content using the soil bulk density (Tobergte & Curtis, 2013);

6.3.4 Climate data

Climatic data were recorded daily using an automatic agro meteorological weather station at KARLO Katumani. Data comprised of solar radiation (Rs), air temperature, minimum and maximum temperatures (Tmin and Tmax), rainfall (P), relative humidity (HR) and wind speed). Minimum and maximum thermometers, Gunn Bellani, hygrometer and anemometer were used for measurement of air temperatures, solar radiation, humidity and wind speed respectively. The weather data were used to compute ETo of common bean using the FAO Pennman-Monteith equation (Equation 3.2) (Allen *et al*., 1998; Hsiao *et al*., 2012), as outlined in Chapter three. Grain yield (kg/ha) and water use efficiency were calculated using Equations 3.3 and 3.4 respectively, as outlined in Chapter three.

6.4 Statistical analysis

Data on bean yield and WUE were subjected to a two-way analysis of variance (ANOVA) using Genstat 14th edition software statistical package at alpha 0.05. Mean separation was carried out using Duncan Multiple Range Test (DMRT). The experiment model was as followed 4 × 3 split- plot design.

6.5 Results and discussions

6.5.1 Soil characteristics

During the experiment under the two cropping season (SR and LR) rains season in 2016 to 2017, the initial soil characteristic suggest that the soil of the study area had an acidic pH and low organic carbon to nitrogen ratio and had phosphorus in low to medium quantities for both LR and SR season (Table 5.1 of Chapter five) which indicate the characteristic of luvisols in the study area (Karuku and Mochoge, 2016). However, rating for phosphorus levels in the study area range from 20 - 200 as medium to very high while 0 - 20 as low to very low (Gicheru and Ita, 1987). The texture of the soil is sandy clay loam with a slow hydraulic conductivity and a high bulk density indicating compaction either due to previous tillage practices or by grazing animals' base on the mixed cropping system or human induced activities. Initial soil moisture content (Table 5.1 of Chapter five) for both season were 1.83 $m^{-3}.m^{-3}$ and 1.21 $m.^{-3}m^{-3}$ this moisture content (Table 5.1 of Chapter five) is as a result of rainfall before planting.

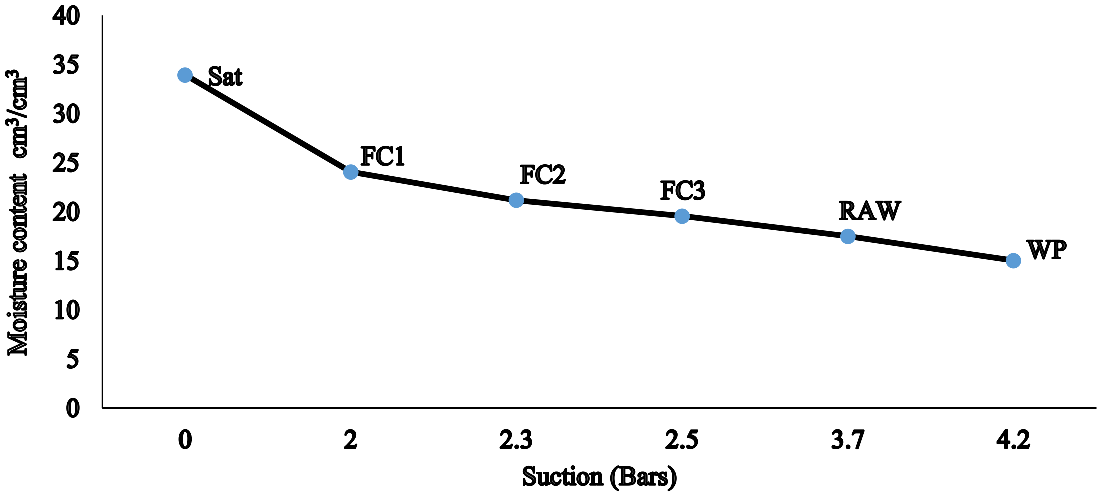
These results implies that the initial moisture content for the SR season was higher than that of the LR due to precipitation received during the onset of the cropping seasons. In this experiment, it was prudent to evaluate the soil nutrient status to understand other factors hampering WUE and grain yield given the fact that the two work together to enhance agricultural productivity. As a result of the wider scope of agricultural WUE, the use of agronomic and biological solution must be considered on a broader level (Deng *et al*., 2006). However, in arid and semi-arid areas, nitrogen plays a vital role in improving agriculture WUE while phosphorus assist plants in deep extraction of water from soil layers (Zhong and Shangguan, 2014). From the initials soil characteristic (Table 5.1 of Chapter five), di-ammonium phosphate (DAP) 80 kg/ha and rhizobium inoculant (USDA 2667) at the rate of 150g/15 kg legume seeds, were used as soil amendments to improve the soil before planting during both seasons.

The WUE biomass results for both seasons after the application of these amendments can be seen in (Table 5.3 of Chapter five). During the drought period (SR), GLPX92 had the highest WUE under CT system while during favorable season (LR), KAT/B1 had the highest WUE under (NT) followed by KATRAM. This is as a result of moisture infiltration in the soil due to the rate of soil inversion for favorable root movement to access the little moisture content in the soil for photosynthesis and that it may be probably that GLPX92 can strive under low moisture condition than the other varieties while KAT/B1 and KATRAM performance better during the LR. Moreover, this indicates that these varieties have low resilience to moisture deficit or could be as a result of low evapotranspiration due to leaves canopy. Under No-till practice, the keeping intact of soil pores helped conserved enough soil moisture for crop growth as compared to CT system.

These results, agrees with Sharma *et al*. (2015), Turner, (2004) and Wang *et al.* (2016) who reported that increased use of chemical fertilizer in dryland farming double grain yields and WUE. The difference in WUE during both seasons could be as a result of increased temperature during the drought event under the SR marked by erratic rainfall while the LR had above average rainfall of 380 mm than the normal 301 mm thereby increasing soil moisture content for plant growth (Figure 5.1 of Chapter five).

6.5.2 Soil moisture retention curve

The potential failure curve (pF) illustrates the moisture retention for the soil in the experimental site for the two cropping season (Figure 6.1). However, research has shown that not all plant have the same wilting point because roots distribution are not uniform in soil as such, moisture absorption from the soil by plant roots differ (Çakir, 2004; Capacity, Point, Water and Range, 2014). Moreover, depending on the soil textural class, the pF curve shows tremendous value as early warning tool reminding of critical point in moisture levels during plants phenological stages under rainfed environment. This curve helps field managers take preventive measures to avoid crop failures during production. However, pF curve in water management during crop production will not only be able to increase WUE but can facilitate the structural adjustment needed by agriculture (Deng et al., 2006). Soil of the study area read field capacity as pF 2 to pF 2.5 and relative available water (RAW) at pF 3.7 or 5.0 bar and wilting point at pF 4.2 or 15.0 bar (Figure. 6.1). Due to high evapotranspiration rates in East Africa and high stress factor on crops, pF 2.3 to 3.7 can be suspected to give more accurate value of the actual available soil moisture in the experimental area.



Note: Sat-saturation, FC – field capacity, RAW – readily available water, WP – wilting point

Figure 6.1: soil moisture retention curve for early warning sign

6.5.3 Soil moisture content at different phenological stages during the two cropping season (SR and LR) rains

Soil moisture trend was high during the LR as compared to LR (Figure 5.2 of Chapter five), and decreased towards the flowering stage (28 DAP) days after planting and later increased to podding stage (42 DAP) and decreased towards harvesting stage (70 DAP). Moisture trend intercepted at 42 DAP (podding) and increase at 56 DAP (maturity) with the SR and decreased at 56 DAP (maturity) with the LR and finally decrease at 70 DAP (harvest) with both (LR and SR) season. Moisture trend in the growth stages of crop is very important to yields and WUE of crops. During this study, results of crop moisture trends showed variations during various phenological stages. This could be as a result of erratic rainfall variability experienced during both seasons (Kisaka *et al*., 2015).

However, varieties did not influence moisture trend at the various growth stages but tillage influence moisture trend at the various stages of crop growth. This could be as a result of climatic effects due to drought causing rainfall variation and increased temperature experienced in semi-arid areas. In the study area, rainfall drop from 283 mm to 164 mm for the SR below the average rainfall of 283 mm while the LR was above average from 301 mm to 380 mm. However, yield losses associated with drought at different crop growth stages of plant development have been looked at by many studies (Farooq *et al.*, 2012; Aslam *et al*., 2015). This could be one of the causes of low yield and WUE during the both season. Negassa *et al*. (2012) showed that crown root initiation and anthesis as the two stages in which losses from drought stress can be more critical in wheat.

Moreover, Vaghasia *et al*. (2010) reported increase in moisture supply leading to increase in water use. This could be the cause of the variation in biomass and grain yields during the LR season as a result of higher rainfall compare to the SR season Figure 5.1 of Chapter five. Çakir, (2004), reported that between two moisture stress treatments, stress given at flowering stage cause reduction in pod yield while reduction in grain due to moisture stress imposed at pod development stage. During this study, similar trend was observed at various phenological stages especially during flowering and podding stages for both season (SR and LR) rains Figure 5.2 of Chapter five, where crops experience moisture stress before reaching the podding stage and there on to maturity. This could probably be one of the many causes of low production in many semi-arid areas of Kenya as a result of variation in climate leading to drought and low rainfall.

6.5.4. Effect of varieties on grain yield and WUE biomass

From this study, it was observed that season influenced grain yield WUE ($P < 0.001$) and there was also variations observed among the treatments declining with GLPX92, KAT/B1, KATX56 and KATRAM as well as with tillage NT, CT and MT Figure. 3. Moreover, among these varieties, GLPX92, differed in grain yield WUE with KATRAM and not with KAT/B1, KAT56 under the same tillage systems and seasons Figure. 6.3. However, lower and higher WUE of grain yield was observed during the SR and LR season as followed GLPX92 (27.5

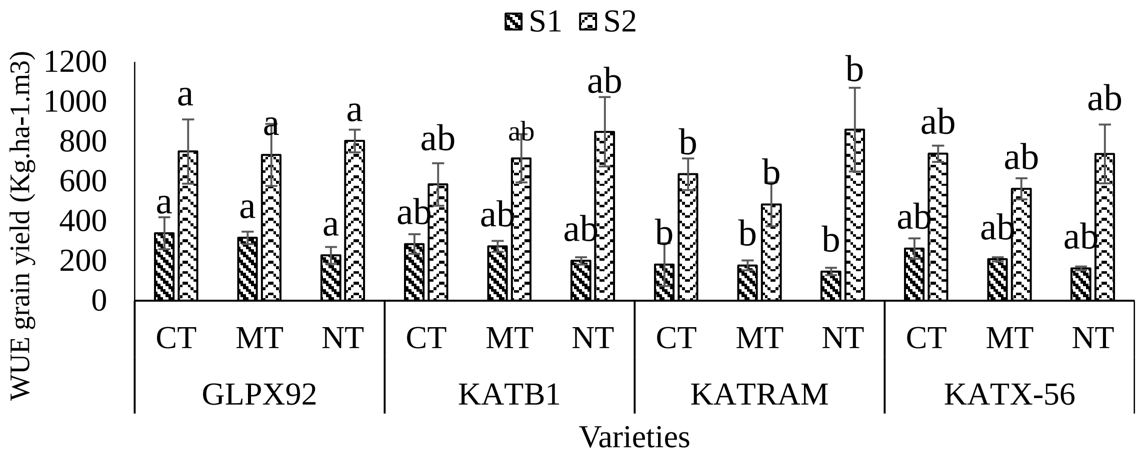
Kg.ha^{-1}), KATB1 (23.9 Kg.ha^{-1}), KATRAM (22.5 Kg.ha^{-1}) and KATX-56 (25.4 Kg.ha^{-1}) and GLPX92 (92.8 Kg.ha^{-1}), KATB1 (77.8 Kg.ha^{-1}), KATRAM (89.5 Kg.ha^{-1}) and KATX-56 (94.6 Kg.ha^{-1}) respectively with the LR yielding higher as compared to the SR Figure 6.3.

This increased WUE grain yield during the LR season is as a result of increased soil moisture content received by increased precipitation as compared to the SR season marked by intense drought with increase in temperature Figure. 6.3. However, crops performed better in NT followed by CT and MT respectively during the LR while during the SR, crops performed better under CT tillage system followed by MT and NT. This is due to season and the type of tillage practices that will conserved increased moisture content for crop production and it also depend on the system that reduce soil moisture evaporation. This was due to the loosing of the soil and breaking apart any obstacles beneath the soil surface for easy moisture infiltration and easy access of moisture in the rooting zone for moisture uplift as reported by (Whitmore *et al.*, 2009).

However, varieties had no influence on grain yields WUE ($P = 0.151$, Figure 6.3) while interaction between varieties × tillage did not influence grain yield WUE ($P = 0.631$). (Kosova *et al*., 2014), reported the dominance of one varieties over another to be due to genetic characteristic like grain yields, hydraulic lift and resistance. According to Ruggiero *et al.* (2017), these responses strongly impact (WUE). This could be the level of supremacy GLPX92 exhibited over KATRAM during the two cropping season LR and SR) that were so fair and harsh for crop production in semi-arid terrains like Machakos County.

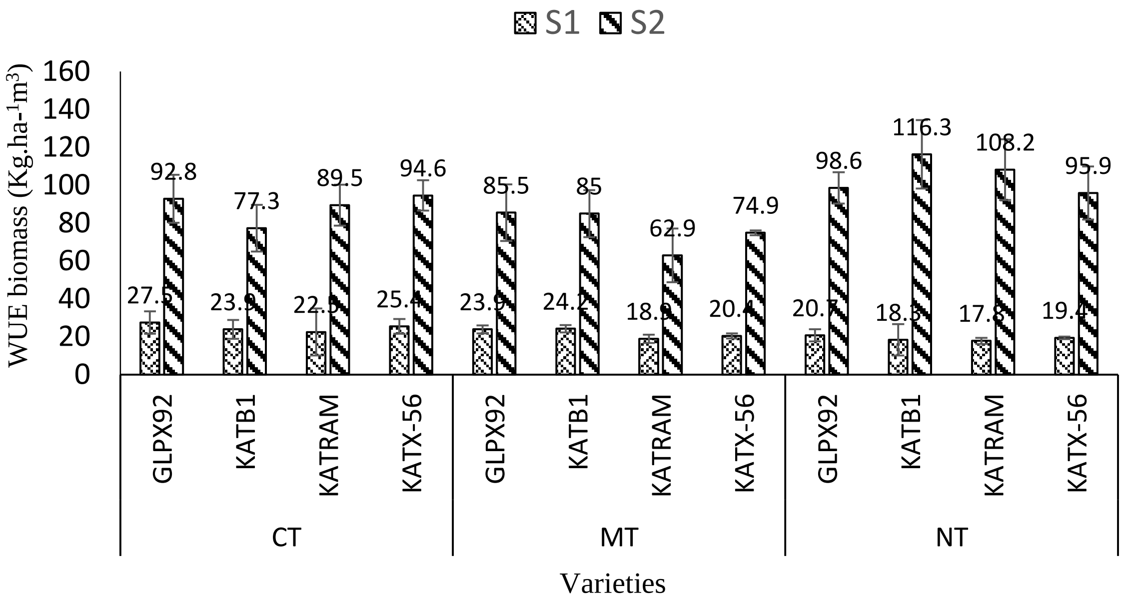
Under the two cropping season (SR and LR) rains, varieties had no significant difference on biomass WUE ($P = 0.604$, Figure 6.4). Tillage also did not influence biomass WUE ($P = 0.320$, Figure. 6.4), neither did interaction between tillage × varieties influence biomass WUE. However, season had influence on biomass WUE ($P < 0.001$, Figure. 6.4) with higher biomass among varieties during the LR as compared to the SR season decreasing with GLPX92, KATX56, KATRAM and KAT/B1 under (CT), GLPX92, KAT/B1, KATX56 and KATRAM under (MT) and KAT/B1, KATRAM, GLPX92 and KATX56 under (NT) respectively.

However, interactions between tillage × season also influenced biomass WUE (P = 0.010) as is indicated above. Moreover, the interactions between varieties × season did not influenced biomass WUE but there were variations among treatments in biomass WUE. The aboveground biomass WUE was generally higher than that of the grain yield WUE for both cropping season in 2016 and 2017. This could be as a result of higher evapotranspiration due to drought caused by climatic variations during the two cropping season. Moisture stress also causes reduction in biomass yield during intense drought during the SR season. Polania *et al.* (2016) reported that drought stress reduced both WUE and biomass and grain yield. Beebe *et al*. (2014) reported harvest index to be reduced by terminal drought stress. This report agrees with Beebe *et al.* (2014) in which drought during the SR season cause crop failures and reduction in crop yield and disagree with Ruttanaprasert *et al.* (2016) that drought increase harvest index in some cases. However, from this study, GLPX92 proved dominant over KATRAM and not with KAT/B1 and KATX56 during the both seasons (SR and LR). This indicated that KATRAM was the least performing varieties during both seasons. However, in other research, "Economic models of biomass production for bioenergy generation," (Davis *et al.*, 2014), identified biomass yield as the most important factor to determine economic viability.



Note: Bars with the same lower case letters are not significantly different at P < 0.05. Whereas bars with different lower case letters are significantly different at *P* < 0.05. CT – conventional tillage, MT –minimum tillage, NT – no-till, S1- season one, S2- season two.

Figure 6.2: Effects of varieties on grain yield WUE.



Vertical bars represent standard error of means. S1- season one; S2- season two, CT- conventional tillage, MT- minimum tillage, NT- no-till

Figure 6.3: Effects of varieties on above- ground biomass WUE

6.6. Conclusions and recommendations

Seasons had influence on grain yield and above ground biomass WUE, and these influences were as a result of moisture stress due to drought and higher temperatures and rainfall variation. The difference observed among GLPX92, KATB1 and KATX56 were not significant and does not justify the supremacy of GLPX92 above KATB1and KATX56 but conversely, it proved supreme over KATRAM. The increased grain yield and biomass WUE could be attributed to some environmental, physiological and morphological factors of which further research needs to be conducted. However, it was observed that GLPX92 during both season had higher grain yield and above ground biomass WUE than KATRAM which was hypothesized to be due to genetic characteristics which needs further research. Moreover, it was generally understood by this study that drought is the prime factor of moisture stress in crop production during cropping seasons, hence, reduces grain yield and above ground biomass WUE based on the region.

Finally, selection of varieties for production in these regions should be based on the season and tillage practices apart from soil infertility that can be remediated with chemical fertilizers and agronomic practices. Soil of the study area read field capacity as pF 2 to pF 2.5 and relative available water (RAW) at pF 3.7 or 5.0 bar and wilting point at pF 4.2 or 15.0 bar Figure. 1.1. Due to high evapotranspiration rates in East Africa and high stress factor on crops, pF 2.3 to 3.7 can be suspected to give more accurate value of the actual available soil moisture in the experimental area.

CHAPTER SEVEN

General discussion, conclusions and recommendation

Machakos is a semi-arid faced with lots of production challenges caused by the factors of climate change such as drought and soil infertility. This has caused many rural household to be so miserable and reluctant in the selection of varieties that have the coping mechanisms as these events like drought occurs. Based on these crop production constraints in sub-Saharan Africa (SSA), researchers have been working overtime to generate improved drought-tolerant bean varieties geared towards the improvement in production and productivity. As a result, many varieties have been disseminated by Kenya Agriculture Livestock and Research Organization (KALRO), the Ministry of Agriculture, Dryland Seeds Company to farmers.in the study to enhance their capacity. Despite the dissemination, adoption is still a challenge Gichangi *et al.* (2012) reported adoption depend squarely on the level of preferences of the household and the area covered.

Hence the reason to measure adoption by respondents' preferences in Machakos County that is so hilly with erratic rainfall and annual drought occurrence is crucial in decision making process. Moreover, from the survey conducted, it was observed that breeders and extension officers have not taken farmers' preference criteria seriously hence motivating the low adoption of farmers to these drought tolerant varieties. This implies that farmers are stakeholders and as such must be heard in production decisions because they are the front liners in production. More besides, when policy makers disregard the preference criteria of farmers, it creates a propensity of farmers shying away from these new varieties because they look strange and creates more doubts in their minds of which they wouldn't want to put their labor and cash at risk with something they do not know. However, it is based on these backdrops this study deemed it prudent to have farmer's inputs in the selection of varieties aimed at increasing their desired to adopt to and work with varieties and many others they have chosen to increase productivity of these drought tolerant common bean varieties.

In Chapter Four, a focus group discussions was conducted with the farmers and majority of them preferred the four varieties as stipulated in Table 4.5 based on high grain yield, high selling rate on the market, early maturity during harsh climatic conditions and high water use efficiency. Elias *et al*. (2017) argues the need to give emphasis to participatory research which is farmers' inclusive, technology preference criteria and priorities seriously. This could be the reason most farmers lack trust in the improved varieties due to mismatch in preference criteria. Hence, involvement of all actors using this approach will make adoption beneficial and successful.

However, age was considered an important component of the household demographics factors that best explains structure in the sample population. In traditional societies, age explains the individuals' position in the society Kecskemeti, (1996) hence implies that older folks are more comfortable in the usage of ancient methods than modern technology (Nankya *et al.*, 2017). In Chapter Four, level of education among gender was used as a measure to determined farmers ability to gain, developed and use information related to drought tolerant bean varieties production hence increase the chances of adoption of production of drought tolerant bean varieties (Indimuli, 2013). From this study, the understanding was that more than half of the farmers were literate thereby negatively affecting adoption and production of drought-tolerant bean varieties (Table 4.1, Chapter four). The Pearson statistic of gender of the household head indicate statistical significant relationship among drought tolerant bean farmers in the study area and awareness of farmers and preference indicated a positive correlation among drought tolerant bean grower and adoption (Table 4.6, Chapter four). In other studies, Asfaw Negassa *et al*. (1977) and

Mwanga *et al.* (1998) reported positive and significant relationship of education with adoption and production of technologies. Conversely, in the study, "Assessment of Production and Marketing of Climbing Beans by Smallholder Farmers in Nyanza Region, Kenya" Gichangi *et al.* (2012) reported insignificant difference in educational status among them.

Results from the logistic regression coefficient test indicate that sources of information in relation to social institutions did not influence farmers' preference (Table 4.5, Chapter four). According to Gichangi *et al*. (2012) credit access is one way to improve farmers' access to new and improved agriculture technology. However, credit access of farmers is indicated in (Table 4.2, Chapter four) and majority of the farmers in the study area complained about credit constraints indicating impediment to higher production and adoption to improved varieties.

The soil textural class was sandy clay loam with acidic pH like other semi-arid areas. In Chapter Five, the soil chemical analysis, the hydraulic conductivity of the soil, the bulk density, initial soil moisture content and percentage sand, silt and clay at the beginning of the experiment were described (Table 5.1 in Chapter five). The soil had low Organic carbon and Nitrogen levels and a very low CEC but medium quantity of Phosphorus and chemical bases and the Al was high but not toxic. The study area falls under agro-climatic zone IV which is described as medium to marginal (Jaetzold *et al.,* 2006). Rainfall is bimodal that is from (March –May) refer to as Long rain (LR) and from (October-December) as the Short rains (Rao and Okwach, (2005); Recha *et al.* (2012) which is more reliable for production.

During the experimental work in Chapter five and six, soil moisture content varied between seasons and depth and not tillage systems (Table 5.2), which could be as a result of climate change impact Valizadeh *et al*. (2014) like drought, temperature rise and decreased rainfall that is so severe in hot and dry areas. In the study area, soil moisture was measured after every two weeks for the both season and moisture variations was observed. Moisture increase in the 40-60 cm depth and this could be as result of rainfall, crop water uptake, transpiration Karuma *et al.* (2014) as well as evaporation and deep percolation. However, result from both Chapter five and six, showed that tillage had no influenced on grain yield but season influenced grain yield which implies that climate change effects due to drought and reduce rainfall could be attributing to this which agrees with Shittu *et al.* (2017). In addition, low moisture content and transpiration reduce plant growth rate and the final grain yield. The seasons also influenced the yields and WUE while the interaction between tillage × seasons also influenced grain yield and WUE. This could be attributed to the type of tillage practices and climatic factors.

During this time of the experiment, specifically the short rain season (SR) there was an event of drought leading to crop failures and low grain yield. Additionally, tillage and varieties did not influenced grain yield and WUE but there were some variations in yields and moisture content during the phenological stages of crop growth decreasing with GLPX92, KATB1, KATX56 and KATRAM but was insignificant. GLPX92 had higher yield in the both season but was not significant to KATB1 and KATX56 but there was significant difference found between GLPX92 and KATRAM in both grain yield and WUE in both chapter five and six (Figure 5.4 and 6.2) respectively. Moreover, biomass and WUE biomass there was no significant difference found among the varieties. However season had significant influence on grain yield and WUE. Varieties and season had no influence on grain yield and WUE. This could be as a result of the semi-arid nature of the study area as reported by (Wang *et al*., 2016). Moreover, Busari *et al*. (2015) reported that tillage impact on yield is related to its effects on root growth, water and nutrient use efficiencies and most importantly agronomic yield.

From this study, there exist drought tolerant bean varieties that farmers are currently growing in Machakos County, Eastern Kenya. Despite the existence of these varieties, production constraints, especially drought, makes farmers to preferred mixed cropping these drought tolerant bean varieties with other crops and livestock production on a minimum land size of 1-2 acres to avoid total crop failure so as to have food in the homesteads. Moreover, most of them acquired seeds of improved varieties from relatives, other farmers and research organizations or from local markets.

However, the results from this study showed that conservation tillage systems is the best option for yield of different drought tolerant bean varieties and WUE in Machakos County, depending on the season. This result also support hypothesis number three which state "Conservation Agriculture positively influence the WUE and increase yield of different drought tolerant bean varieties in semi-arid areas of Machakos County, Eastern Kenya'. Also in support of the second hypothesis, different drought tolerant bean varieties did not differ significantly in their WUE during the both SR and LR (Chapter six), indicating that the four varieties will performed well under good irrigation systems or under rainfed system where there is favorable and adequate rainfall to support production hence increasing yield and WUE of these crops.

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APPENDICES

Plate 1: Taking soil moisture readings

Plate 2: Harvesting of crop from experimental field

Profiling adoption information on the selection of drought tolerant common bean varieties and their water use efficiency (WUE) among Smallholder farmers in Machakos County, Kenya.

Collected data in this survey will help in creating database of the adoption of drought tolerant common beans varieties and their water use efficiency (WUE) among small-scale farmers to inform future researchers, on the challenges underlining the adoptions of drought tolerant common bean varieties in semi-arid and arid regions as well as national government policies. Information about the respondents will be confidentially secured and shall be used only for the purpose of this survey. Information provided shall not be shared with any third party whatsoever without the consent of the respondent. Kindly just provide honest and correct information. Your assistance and co-operation will be highly appreciated.

Questionnaire

Part 1: Farmer's details

1.0 Kindly fill the following details:

Name: …………………………………………………………………..

Tel no.: …………………………………………………………………..

Date of birth: …………………… Age: ……………………………..

(Tick appropriately)

Sex: Male ☐ Female ☐

Marital status: Married ☐ Divorced ☐ Separated ☐ Single ☐ Widow/widower ☐

Educational level: Primary ☐ Secondary ☐ College ☐ University ☐ None ☐

Sex of the head of household: Male ☐ Female ☐

Main occupation: Civil employment ☐ Farming ☐ Casual labor ☐

Number of children in the age bracket

Age bracket	Number
0-5	
6-10	
11-15	
16-20	

21-25	
26-30	
Above 30	
Total	

Part 2. Information on common beans grown Katumani, Machakos

1. What type of crops do you grow? --
2. Under which cropping system? Mixed cropping ----------------, intercropping --------------, solely cropping ---------------------.
3. Do you have information on common bean varieties? If yes which One? ---.
4. Are these varieties available? Yes ------ or No ---------- (Ticked appropriately)
5. If yes, what is the cost per Kg? --.
6. What fertilizers do you use? ---
7. Cost of fertilizers (kg) ---.
8. What tillage practices do you carry out? Conventional ------------------, minimum -----------, and zero tillage -------------- (Ticked appropriately).
9. What is the yield per hectare? ------------------------- (kg)
10. What are the main challenges you faced during production? ---
11. What are the minor challenges you faced during production? ---.
12. Have you heard of any drought tolerant common bean varieties? Yes ----------- or No ---------
13. If yes, Give example: --
14. Source of information on these drought tolerant common bean varieties ---
15. Have you ever grown some of these drought tolerant common bean varieties? Yes ------- or No ----------
16. If yes what are the varieties grown? ---
17. Are you currently growing these drought tolerant common bean varieties? Yes ------- or No -------
18. If No, will you prefer growing it? Yes ------- or No ---------

19. If No, why will you not prefer growing it ---
20. What is the planting season of the common bean crop in this area? --

Part 3: Common bean production and challenges

1) What variety of common bean do you grow?

………………………………………………………………………………………………

2) Where did you get the seeds from? (Tick appropriately)

Other farmers ☐

Training institutions ☐

Research institutions ☐

Family members ☐

Own material ☐

3) What are the reasons for selecting that variety? (Tick appropriately)

High grain yielding ☐

High biomass yielding ☐

Improves soil fertility ☐

4) Improved variety ☐

Water use efficient ☐

☐

Selling ☐

Others (Specify) ☐ ……………………………………………

Part 4: Extension services

a) Are you a member of any of the following financial institutions? If yes, tick appropriately.

Commercial Bank ☐

SACCO ☐

Table banking group ☐

Micro finance ☐

Others (Specify) ☐ ………………………………………………………….

b) Do you have accessibility to credit services? Yes ☐ No ☐

c) What challenges do you face in accessing credit services? (Tick appropriately)

High interest rate ☐

Lack of security ☐

Fear ☐

Not in need of a loan ☐

Others (Specify) ☐ …………………………………………………………..

d) Which agricultural based Organizations promote Drought tolerant common bean varieties in this region? ………………………………………………………………….

(e) What is the source of information you use in growing Drought tolerant common bean varieties (Tick appropriately)

Own experience ☐ NGOs ☐ Church ☐ Government of Kenya ☐

Friends & relatives ☐ Agricultural research ☐

Part 5: Land

a) What is the total land size of your farm? ……………………………………….

b) What is the land tenure system of your farm? (Tick appropriately)

Leasehold tenure ☐

Freehold tenure ☐

Community land ☐

c) Who owns the land? (Tick appropriately)

Male ☐ Female ☐ If family land, father ☐ mother ☐

☐ Grandfather ☐ grandmother

THANK YOU. THE END.

We are highly gratified for finding time to exhaust this questionnaire. We gracefully appreciate and value your answers. Thank you ever so much. We wish you abundant achievements in your daily endeavors. God bless you.