EFFECT OF TILLAGE METHOD AND MULCH ON SOIL MOISTURE RETENTION, CROP GROWTH, NODULATION AND YIELD OF GREEN GRAM IN SEMI-ARID KENYA

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

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DEDICATION

This thesis is dedicated to my lovely mom Elizabeth Anek Hakim who throughout my life has been a solid rock in my upbringing and support right from my preprimary education to this level, my late father Hakim James Ola'a who succumbed in an accident in the same field of agriculture, a practice I have chosen to pursue. To my lovely wife Scovia Aber who throughout the difficult time encouraged and supported me and took care of or lovely daughter Alessia Lagum.

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LIST OF ABBRRVIATIONS AND ACRONYMS

ANOVA	Analysis of variance
ASALs	Arid and semi-arid lands
CT	Conventional tillage
ETo	Potential evapotranspiration
FR	Furrow-ridge
HI	Harvest index
KALRO	Kenya Agricultural and Livestock Research Organization
Kg	Kilogram
LSD	Least significant difference
NARL	National Agricultural Research Laboratories
RCBD	Randomized Complete Block Design
SSA	Sub-Saharan Africa
SOM	Soil organic matter
USAID	United States Agency for International Development
WUE	Water use efficiency

GENERAL ABSTRACT

Agricultural productivity in arid and semi-arid areas has continued declining due to low unreliable rainfall, declining soil fertility, and poor agronomic practices. This study was conducted with the aim of contributing towards enhanced green gram productivity in the ASALs through use of conservation tillage methods and mulch application. The experiment had three replicates in a split-split plot arrangement where a randomized complete block design (RCBD) was used. Zero tillage (ZT), conventional tillage (CT) and furrow-ridge (FR) were the three main tillage systems that composed the main plots. The split plots were no mulch (0 t ha^{-1} (control) and mulched 3 t ha^{-1}), while in the split-split plots contained variety N26 and KS20 of green gram. Data collected for percentage (%) emergence, days to 50% flowering, 75% maturity, plant height, number of primary branches, nodules and their dry weight, root and shoot biomass, number of pods plant, number of seeds per pod, grain weight and harvest index. Soil moisture content was determinedby collecting soil samples at 0-30 cm depth at (vegetative, flowering and maturity) growth stages.The data were subjected to general analysis of variance using GenStat 15th statistical package. Means were separated using Fisher's least significant difference (LSD) at 5 % probability level. According to the findings, tillage method together with mulch had significant effect on crop phenology, growth parameters, yield and its components. Furrow-ridge performed better than zero tillage and conventional tillage. Variety KS20 had more nodules than N26 under furrow-ridge mulched with mulch. Variety N26 under the same treatment had more branches, higher height, yield in both experiment sites. Tillage method and mulch significantly affected moisture content at every stage of green gram growth. Significant higher soil moisture was recorded in furrow- ridge, then no tillage with lowest recorded in conventional tillage. Mulched furrow-ridge as well as zero tillage were the better techniques with increased yield of green gram and also the most efficient techniques for soil moisture conservation in Katumani and Mwea. High water use efficiency was recorded under furrow-ridge mulched with 3 t ha^{-1} residues of plants compared to mulched conventional tillage plots and zero tillage and those without mulch. It is suggested that combination of furrow-ridge with mulch application can potentially increase green gram growth, nodulation and yields in arid and semi-arid environments. This study therefore recommends this practice to be incorporated into smallholder farming systems to increase resilience against drought.

Key words: furrow-ridge, zero tillage, phenology, growth, yield and yield component

CHAPTER ONE: INTRODUCTION

1.1 Background information

Green gram (*Vigna radiata* (L) Wilczek originated from India and Central Asia (Deb Roy *et al.,* 2017). It has been cultivated in these regions in the earlier days and continued to be cultivated in India and central Asia as an important legume crop up to date (Swaminathan *et al*., 2012). Currently green gram cultivation has spread worldwide in Asia, South America, Australia and Africa and has been identified as high yielding pulse (Karuppanapandian *et al.*, 2006; Itefa *et al,* 2016). Its production is (90%) done in Asia with India taking nearly 50% of its world production and consumption (Mulika *et al.*, 2019). Other Countries like Thailand have intensified the production by 22% between 1980-2000 (Lambrides and Godwin, 2006).

Green gram seed is more palatable with high nutrient content, easily digestible and non-flatulent compared to other pulses (Mulika *et al*., 2019), and its ability to fix soil nitrogen (Chauhan *et al*., 2018). Green gram is an early maturing and drought tolerant crop that can do well in low rainfall below average of 600mm and in temperatures range between 20 to 40°C and 28–30°C as optimum(Eswaran and Senthilkumar, 2015; Swaminathan *et al*., 2012). Green gram is one of the valued leguminous crops that strive in areas where drought is a major problem to production but suffers serious damages in drought frequent conditions (Eswaran and Senthilkumar, 2015). Green gram global productivity is about 406.98 kg/ha which is very low (Roy *et al.*, 2017).

Green gram is produced mainly in the ASAL regions of Kenya with low and unreliable rainfall as food and cash crop (Mulika *et al.,* 2019). Most of its production is done by smallholder farmers under rain-fed conditions with about 90% produced in the drier areas of Machakos, Kitui, Makueni, Mbeere,Tharaka and Meru counties (Karimi *et al.,* 2019). Despite of all the potential benefits of green gram, its production has been low in Kenya due to number of factors that ranged from climatic conditions, pest and diseases, poor soil fertility and poor agronomic practices (Karimi *et al*., 2019).Kenya's land is covered by over 80% arid and semi-arid lands (ASALs) with more than 65% of its inhabitants being poor and depend on relief aid from the government and humanitarian agencies(Kwena *et al.*, 2017). Crop yield in these areas is low due to low rainfall which is contributed by climate change and variability (Omoyo *et al.*, 2015). The ASAL regions of Kenya continue to experience unreliable amount of rainfall with high evapotranspiration of about (2000– 2300mm/year) (Kisaka *et al.*, 2015). Soil in the ASALs have poor structure and shallow with weak stability which allows them easily eroded and have low macro and micronutrients (Kinama *et al.*, 2005). Hightemperatures and insufficient amount of rainfall has affected crop production negatively as crops become vulnerable to pest and diseases leading to crop failures (Recha *et al.*, 2012).

Tillage practices is key factor that contribute to soil moisture loss, soil erosion through water andwind medium as well as increase of production cost (Johnson *et al*., 2018,). Many studies carriedout have shown that conservation tillage and use of mulch potentially contributes to moisture retention, soil erosion control. Zero tillage conserves water through increased infiltration, reduce surface evaporation and control surface run-off therefore promoting effective crop productivity inASAL environments (Giller *et al*., 2011; Johnson *et al*., 2018). Furrow-ridge conserves moisture by collecting water in the furrows for plants use and promote efficient use of fertilizers by preventing leaching (Kristensen and Sorensen, 2013).

Application of mulch conserves soil moisture and regulate temperature in the soil which increasescrop yield due to available moisture for crop physiological activities (Kader *et al.*, 2017).Furthermore, mulch application reduces erosion which is a common problem in areas that receivesless rainfall and this allows water to infiltrate into the soil (Bhardwaj, 2013). In addition, mulch smothers weed in the field (Siipilehto, 2001).
The purpose of this study was to evaluate the effects of tillage methods and mulch application on soil moisture retention, crop growth, nodulation and the yield variety N26 and KS20 of green gram in Katumani and Mwea.

1.2 Statement of the problem

Green gram is majorly grown in the ASALs, but it is faced with many production constraints (Kihoro *et al*., 2016). Low and unreliable rainfall is the key production challenge to green gram production (Karuma *et al*., 2012). Low and unreliable rainfall in Kenya is caused by variability and change in climate which has continuous effect on crop yield across the region especially in the Eastern part of Kenya (Roy *et al.*, 2017).

Soil water stress affects plant vegetative establishment which plays critical role during grain setting(Andrade *et al*., 1991, Andriani *et al.*, 2008). High temperatures in ASAL increases evaporation especially at the beginning of the season and may continue due to the low seasonal rainfall (Kinama*et al.*, 2005). Evapotranspiration in the ASAL regions of Kenya is recorded to be about 2000–2300mm/year which is high and affects yield of crops (Kisaka *et al.*, 2015). Water lost through soil evaporationgenerally accounts for 30-50% of rainfall water (Cooper *et al.*, 1987). About 10-25% of rainwateris lost through surface runoff and nearly 10-30% of rainfall water is lost through drainage due to soil with low holding capacity (Casenave and valentin, 1992; Rockstrom *et al*., 2003).

Productivegreen water flow through transpiration accounts for 15-30% of rainfall (Rockstrom *et al.*, 2003). In this regard nearly 70-80% of rainwater is considered lost to the cropping system as non- productive green water flows and a blue water flow (Rockstrom *et al*., 2015). Soil in the ASALs is poor in fertility with shallow and poor structural stability which makes them susceptible to erosion andloss of macro and micronutrients (Kinama *et al.*, 2005; Chepkemoi *et al.*, 2014). Low yield in the semi-arid of Kenya has been reported due to continuous cultivation without fertilizer application to replenish used nutrient in the crop cycle (Chemining'wa *et al*., 2007). Furthermore, the ASAL experience salinity stress which impede germination and cause stunting in crops (Itefa, 2016).

1.3 Justification of the study

Managing water loss includes crop management practices and breeding aspect to enable efficient use of the limited water in the arid and semi-arid environments. Zero tillage, furrow-ridge and mulch application play important role in soil moisture conservation and nutrient recycling in the soil (Verhulst *et al*., 2010, Johnson *et al*., 2018). Zero tillage and furrow-ridge increase yield as aresult of nutrient and moisture availability (Micheni *et al*.,2014).

These practices were proven on several occasions in modification of soil water changing aspects which includes infiltration, surface evaporation and run-off control therefore, promoting effective crop production in environments characterized by low and unreliable rainfall (Giller *et al*., 2011; Johnson *et al*., 2018). Zero tillage reduce surface runoff which increases soil water infiltration and increases soilorganic matter and water infiltration (Busari *et al.*, 2015). Zero tillage increase yield and reduce erosion compared to conventional tillage (Devraj *et al*., 2020). Furrow-ridge is known toplay important role in moisture conservation and efficient use of fertilizers as the shape of the ridgeprevent nutrient from leaching by the effect of precipitation (Kristensen and Sorensen, 2013). Furthermore, furrow-ridge reduce soil erosions and enhances organic matter decomposition whichscale up crop yield (Kristensen and Sorensen, 2006; Mitchell, 2009). Gan *et al.* (2013) and Qi *et al.* (2015) reported that furrow-ridge increase water infiltration, improves water use efficiency (WUE) thus increasing yield especially in the ASALs. Application of mulch and effectivemulching techniques increase crop yield and water use efficiency (Chen and Feng, 2013; Memon*et al.*, 2017). Mulches conserve moisture and regulate temperature in the soil which increases yield of crops compared to when bare fields are used (Kader *et al.*, 2017). Soil erosion is one of the common problems in ASALs but with the use of mulch it is reduced (Bhardwaj, 2013). Siipilehto. (2001) and Laurie *et al.* (2015*)* reported that mulch reduces weeds infestation which compete with crops for moisture, nutrient and light.

The use of conservation agricultural practices like zero tillage; furrow-ridge and mulching were seen to improve other crop productivity and soil moisture retention. However, limited studies have been established whether these improved tillage practices can increase green gram productivity inKenya. The findings of this study will go all the way in informing policy maker on the policy formulations concerning the production of green grams, which are geared towards food security. On the other hand, the researchers will be able to breed green grams for increased tolerance to drought, early maturation, and increased production.

1.4 Objectives

The general objective was to contribute to increased green gram yield in the semi-arid environments of Kenya through the use of improved tillage methods and mulch. The study had the following specific objectives:

i. To determine the effect of tillage method and mulch application on growth, nodulation andyield of two green gram varieties
ii. To determine the influence of tillage method and mulch on soil moisture conservation andwater use efficiency of two green gram varieties

1.5 Hypotheses

i. Tillage method and mulch does not have significant effect on green gram growth, nodulation, and yield
ii. Tillage method and mulch does not have significant effect on soil moisture retention and water use efficiency

CHAPTER TWO: LITERATURE REVIEW

2.1 Botany, ecology, and importance of green gram

Green gram (*Vigna radiata* (L) Wilczek belongs to angiosperm dicotyledonous crops in the family Fabaceae (Itefa, 2016). It is an herbaceous crop that grows between 0.25-1 meter in height with deep roots (Kavya *et al.*, 2014). Green gram has an erect to semi erect stem sometimes twines slightly at the top with highly branched long petioles which are rarely lobed with alternate, trifoliate, and deep green ovate leaflets that ranges from 5 to 12cm wide and 2 to 10cm long (Itefa,2016). It starts flowering in 40-60 days and continue for some weeks before harvest with maturedpods which consist of 8-20 globose seeds (Kavya *et al.*, 2014).

Green gram is normally seed propagated and has no seed dormancy issues though hard seed coat sometimes affects germination.Seed are sown through broadcast or dibbling in row with sowing rates of around 5–10 kg/ha for sole crops, and 3-4 kg/ha for intercropping (Swaminathan *et al.*, 2012). In Kenya spacing green gram as a sole crop recommended is at 45 × 15cm for intra and inter space respectively and 50 × 20cm in some cases, at a seed rate between 6–10 kg/ha and sown at a depth between 4–5 cm but can be used in an intercrop with cereals, sweet potatoes, and trees as a relay-crop (Kavya *et al.*, 2014).

This crop originated from India and central Asia (Roy *et al.*, 2017). It has been cultivated in theseregions in the earlier days and continued to be cultivated in India and central Asia as an importantlegume up to date (Swaminathan *et al*., 2010). Currently green gram cultivation has spread widelyin Africa, South America, Australia and in many Asian countries and it has been identified as highyielding pulse (Karuppanapandian *et al.*, 2006, Itefa, 2016). It is an early maturing and drought tolerant crop that can do well in low rainfall below average of 600mm and in temperatures range between 20 to 40°C and 28–30°C as optimum (Swaminathan *et al*., 2012; Eswaran and Senthil Kumar, 2015). It is a short-day plant that performs well in well-drained loam or sandy loamsoil with optimum pH range between 6.5 to 7.5 (Swaminathan *et al.*, 2012). *Vigna radiata* is known with so many names such as Mung beans, Haricot mungo, mchoroko (Swaminathan *et al.*, 2012) and in Kenya it is popularly known as ndengu.

2.2 Economic importance and utilization of green gram in Kenya

Green gram consumption and uses vary from one country to another as harvested green gram seeds are prepared directly, ground into flour, split into dhal, seed coat removed and series of dishes made out of it like soups, bread, porridge, cakes, noodles and even sometimes in making ice cream (Swaminathan *et al*., 2010, Swaminathan *et al*., 2012). Health wise green grams contain dietary fibers which are part of food that cannot be digested therefore playing important role in weight loss which ensures slow release of calories in the blood stream.

Green gram has low- sodium component in raw sprouts and seed therefore, reducing the risk of getting high blood pressure (Kavya *et al*., 2014). It is rich and easily digestible high-quality source of dietary protein, vitamins, and other minerals such as Iron, Magnesium, Phosphorus, Manganese which are very important to our body in the absence of animal nutrients (Machocho *et al*., 2012). It is also used as traditional source of treatment of paralysis, fever rheumatism, coughs, and liver ailments (Kavya *et al*., 2014). Its residues and seeds can also be used to feed livestock and sometimes grown as green manures in the field or as cover crops (Kavya *et al*., 2014). It is an important leguminous crop that helps in maintenance of soil fertility by fixing nitrogen in the soil (Mulika *et al*., 2019).

2.3 Green gram production trends in Kenya

Green gram production in Kenya is mainly done in the drier parts of Machakos, Kitui, Makueni, Mbeere, Tharaka and Meru counties by smallholder farmers under rain fed conditions (Karimi *et al*., 2019). It is an important income generating crop in the eastern Kenya (Wambua *et al*., 2017). Even though green gram is an important dryland crop in the ASALs, its yield has been experiencing decline in the recent years (Karimi et al., 2019). Despite the decline in yield per hectare, yield increased from 91,585t in 2012 to 148, 885t in 2017 (MOA, 2018). Nevertheless, the increase in green gram production acreage and yield by 62% failed to meet food demands of 340 to 500 tons required in Kenya (Karimi *et al*., 2019).

2.4 Green gram production constraints in Kenya

Green gram is among the major crops grown in eastern Kenya but is faced with many productionconstraints (Kihoro *et al*., 2016). Soil water stress is one of the most limiting factors to crop production in the world (Rimski-Korsakov *et al*., 2009). The drier parts of Kenya are known for low, unreliable and unevenly rainfall distribution (Mutune *et al*., 2011; Karuma *et al*., 2012). Thisaffects plant vegetative establishment which plays critical role during grain setting (Andrade *et al.*,1991; Andriani *et al*., 2008).

Poor tillage and agronomic practices affect moisture conservation and encourages soil erosion. However, increase of soil moisture conservation in the soil can be obtained by using tillage practices that enhance infiltration of rainwater and reduce surface evaporation (Karuma *et al*., 2012). Poor soil fertility in the area affects crop yield as a result of continuous cultivation without replenishing the soil (Chemining'wa *et al.*, 2007). Diseases such asanthracnose, yellow mosaic virus, bean rot and pests like bean fly, pod- sucking bugs, aphids,pod boring caterpillar are common constraint to green grams in Kenya (Machocho *et al*., 2012).

2.5 Water use efficiency

Water use efficiency (WUE) can simply be defined as the ratio between grain yield and water use(Johnson *et al*., 2018). Potential evapotranspiration (ETo) can be defined as the difference betweenseasonal cumulative rainfall and soil moisture content at physiological maturity, supposing run- off and deep drainage are negligible (French and Schultz 1984).
Crops management practices and genetic improvement can be done to enhance water uptake, transpiration efficiency for biomass production and harvest index (Condon *et al*., 2004). In this study furrow-ridge, zero tillage and mulch application were used to explore more on agronomic practices that increase soil water infiltration and reduce evapotranspiration especially in semi-aridenvironments. Furthermore, the application of mulch restrict light for weeds to carry out photosynthesis effectively especially at the early stage of weeds establishment between 2-5 weeksand smoothers the weeds (Laurie *et al*, 2015). In this research, WUE referred to the ratio of economic grain yield to seasonal evapotranspiration and has been well described in materials and methods Chapter 4 (4.4).

2.5.1 Soil water balance in the ASALs

Managing water loss includes crop management practices and breeding aspect to enable efficient use of the limited water in drier lands. This practice is being adopted in many semi-arid environments with little and unreliable rainfall like in Eastern Kenya (Johnson *et al.,* 2018). Zerotillage and furrow-ridge increase crop yield as a result of nutrient and moisture availability (Micheni*et al.*, 2014). The use of inappropriate tillage practice may lead to land degradation as tillage practices has the greatest impacts on the environment than any other farming practice (Lobb *et al.*,2007).

Water productivity is a key challenge that needs to be improved by an on-farm water balance (Rockstrom *et al*., 2003). Water lost through soil evaporation generally accounts for 30-50% of rainfall water (Cooper *et al*., 1987; Kinama *et al*., 2005). The value of lost water is more than 50%in sparsely cropped farming system in ASALs (Allen,1990). About 10-25% of rainwater is lost through surface runoff (Casenave and Valentin, 1992; Kinama *et al*.,2007). Nearly 10-30% of rainfall water is lost through drainage due to soil with low holding capacity (Rockstrom *et al*., 2003). The productive green water flow as transpiration accounts for 15-30% of rainfall (Rockstrom *et al*., 2003). In this regard, nearly 70-80% of rainwater is considered lost to the cropping system as non-productive green water flows and a blue water flow (Rockström *et al*., 2015). Water loss through seepage was shown to be very low even when the rainfall was heavy during the Elnino of 1997/98 (Kinama, 1997) and can be treated as trace or negligible.

Ridges and mulch have shown to reduce the effect of rain drops and runoff speed, which helps water infiltrate into the soil. Soil structure plays major role in the capacity of the soil to capture, transfer and store water (Kitonyo *et al*., 2018). Zero tillage and mulch on soil surface increases the stability of soil aggregates (Bronick and Lal, 2005), improving soil structure and facilitating water infiltration and storage (Gowing and Palmer, 2008).

2.5.2 Crop management practices that improve water use efficiency

Adaption of crops to water stressed environments through timing of flowering is one of the key physiological characteristics (Passioura and Angus, 2010). Ideal flowering looks at balancing water use between vegetative, grain set and grain filling requirements (Angus and van Herwaarden, 2001). Agronomic factors like sowing time and nutrition, in addition to breeding can influence crop growth rates that can impact flowering time (Angus and van Herwaarden, 2001). The pre- and post-flowering regulation of crop growth impacts water use efficiency (WUE), harvest index (HI) and final grain yield. High vegetative growth in moisture-constrained environments may cause excessive pre-flowering moisture use that may also reduce reserves at reproductive stage (Van Herwaarden *et al*., 1998).

2.6 Tillage

Tillage is the preparation of seedbed for sowing by plowing using moldboard, animal drawn implements or any tool for soil manipulation (Cowan *et al*., 2016; Johnson *et al*., 2018). Tillage practice breaks soil clods to loosen particles which increase soil aeration and enhance deeper rooting (Cowan *et al*., 2016). It controls weeds, enhances organic matter and manure incorporation in the soil (Johnson *et al*., 2018). However, tillage practice is one of the factors that contribute to soil moisture loss, soil erosion through water and wind medium as well as increase of production cost (Johnson *et al*., 2018,). Therefore, appropriate tillage practices have to be employed to increase infiltration, soil fertility and soil erosion reduction.

2.6.1 Zero tillage

Zero tillage is one of the tillage practices which involve growing crops or pasture without disturbing the soil through tillage. It reduces surface runoff which preserves soil organic matter and increase water infiltration into the soil (Busari *et al*., 2015). Zero tillage has been shown to reduce erosion from 3.1 to 1.9 billion tons compared to intensively ploughed land (Busari *et al*., 2015). The effectiveness of zero tillage is further improved by the application of mulch. Mishra et al. (2011) reported that combining mulch materials with zero tillage improved the soil physical properties and this further led to an increase in crop yield (De Vita *et al*., 2007; Devraj *et al*., 2020).

2.6.2 Furrow-ridge

Ridge tillage plays important role in moisture conservation and efficient use of fertilizers as the shape of the ridge prevent nutrient from leaching by the effect of precipitation that runs down the sides of the ridge (Kristensen and Sorensen, 2013). It also reduces soil erosions and enhances organic matter decomposition. It has been seen in many research reports that ridging maintain or scale up crop yield as well as increasing the economic return while minimizing the use of fertilizer and crop protection pesticide (Kristensen and Sorensen, 2006; Mitchell, 2009). Furrow tillage practice increase water infiltration, improves water use efficiency and crop yield (Gan *et al*., 2013; Qi *et al*., 2015). Ridge-furrow when mulched with plastic film or organic mulch regulates soil temperature (Li *et al*., 2001; Gan *et al*., 2013).

2.6.3 Mulching

The word mulch has originated from German word "molsch" which means soft to decay (Bhardwaj, 2013). It apparently referred to the use of straw and leaves, inorganic material and plastic sheet or life cover crops that cover the soil surface. Mulches are encouraged for use in agricultural crop production because of so many reasons among which water and soil conservation are the main ones (Bhardwaj, 2013). Mulching effectively increase crop yield and water use efficiency as revealed in studies conducted by Chen and Feng (2013) and Memon *et al*. (2017). It conserves moisture and regulate soil temperature which increases yield of crop compared to when bare field is used (Kinama, 1997; Kader *et al*., 2017).

Mulch application reduces soil evaporation which is a major challenge to crop yield in ASALS (Kinama *et al*., 2005). Soil erosion is one of the common problems in arid lands that could easily be controlled by mulching to allow water infiltration into the soil (Bhardwaj, 2013). Mulch application smoothers weeds which would have competed with crops for space, moisture, light and nutrients (Siipilehto, 2001). Mulching materials restrict light for the weeds to carry out photosynthesis effectively especially at the early stage of weeds establishment like 2-5 weeks (Laurie *et al*, 2015).

Organic mulch has been reported to reduce the rate of nitrate leaching (Bhardwaj, 2013). Application of mulch in a field has significant importance on the hydro-physical properties of soil for example Soil organic matter (SOM), field capacity, bulk density of soil, porosity (Kakaire *et al*., 2015). Mulching enhances both macro and micronutrients to the soil (Shahid *et al*., 2014). Nodulation increases with mulch application due to favorable conditions that promotes microbial activities (Singh *et al*., 2011). But when rain is sufficient then mulch will be of less significance to moisture retention but of great value to some of the above stated importance. The benefits of mulch in water harvesting and retention are variable, and depend on rainfall intensity, frequency of precipitation, evaporative demand, and soil type.

2.7 Nodulation in green gram

Nodulation is a complex process through which nodules are formed in the roots of leguminous plants infected by rhizobium bacteria. Nodulation in legume is controlled by various processes which include external; water stress, soil acidity, heat, and nitrate and internal factors also known as auto regulation which controls plant number of nodules through a systemic process that involves the leaves (Voisin *et al*., 2010). Increased nodulation depends on the soil penetrability which could be attributed to soil bulk density. Several studies have indicated that sufficient amounts of water in the soil enhance the nodulation process hence increasing the number of nodules and active nodules (Singh *et al*., 2011).

Furrow-ridge and zero tillage are known for moisture conservation in the soil but have different bulk density in the soil. Number of root nodules reduces with soil moisture stress as rooting and rhizobium bacteria activities are affected (Sangakkara, 2004). Nodules produced per leguminous plant reduces if the growth of root is restricted due to fewer potential sites for rhizobia infection (Kombiok and Buah, 2013). This means in compacted soil with high bulk density rooting and its establishment becomes a problem since penetration for the roots and water availability for absorption is hard for the plant.

Soil moisture plays an important role in roots establishment and creating conducive environment for rhizobium bacteria to carryout infection, since moisture stress affects the bacterial activities. Different tillage method has varying effects on moisture conservation and soil compaction. Soil with high bulk density makes rooting a problem therefore limiting nodulation this is due to compaction (Ayanaba and Nangju, 1993). Conventional tillage may provide a good rooting and nodulation environment when there is an optimum rainfall during the cropping season but when there is water stress then nodulation becomes a problem in conventional tillage but can be corrected by mulch application (Dukare *et al.,* 2017). Mulch increases soil water infiltration this is through providing a shielding effect from solar radiation and water run-off thus increasing water infiltration and retention in the soil.

Higher number of root nodules was observed in organic mulched plots compared to un-mulched plots (Dukare *et al*., 2017). Crop varieties play key role in formation of nodules and nitrogen fixation in the soil Ayanaba and Nangju, (1993). Mulika *et al*. (2019) in their study found out that green gram variety KS20 had more nodules compared to KAT00308 and KAT0039.

2.8 Effects of soil moisture on yield and yield components

Crop growth and yield determination knowledge are important for suitable and more sustainable crop production as it dictates the most suitable management practices, efficient and optimum use of agricultural inputs information and provision of conceptual and screening tools for yield improvement and environmental adaptation (Andrade *et al*., 2008). Moisture plays a critical role in grain setting in crops especially during the branching which determines the reproductive part such as the followers and the pods which determine the number of grains per pod (Andrade *et al*., 2008). Water stress at the reproductive stages, most especially at flowering and pod formation affect seed yield more seriously than any crop stage.

Crops mature faster because of water stress and allocate less biomass to vegetative growth compared to those under favorable conditions (Karkins *et al.*,2012). It was also noted that plant biomass accumulation decreased with water stress (Mnasari *et al*.,2007). The number of grains depends on crop growth during the critical period and dry matter partitioning (Andrade *et al*., 2005). This relationship varies among species depending on the plasticity in the reproductive organs and tolerance to stress during grain formation (Andrade *et al*., 2005). Higher yield has been reported due to available moisture in other tillage compared to others that doesn't conserve enough moisture (Huang *et al*., 2012).

2.8.1 Biomass accumulation in green gram

Biomass accumulation under different tillage methods is related to the moisture availability in the soil, whereby biomass increases with moisture availability compared to biomass accumulation for crops under water stress condition. This is because crop under water stress tend to finish its physiological maturity in a short period ahead of time to avoid failure but with reduced biomass compared to those under favorable condition. Crops mature faster under waster stress and allocate less biomass to vegetative growth compared to those under favorable conditions (Karkins *et al*., 2012). Crops with available soil moisture takes it's normal or prolonged maturity period due to available moisture, hence producing high biomass. Tillage methods affects above the ground biomass due to soil moisture availability stored under different tillage methods (Iqbal *et al*., 2008; Khaemba *et al*., 2016; Parlawar *et al*., 2017). Water stress decreases biomass accumulation in crops (Mnasari *et al*., 2007).

Mulch application serves a great importance to crop growth and soil conservation which include increasing soil moisture retention, regulation of soil temperature and control of soil surface runoff. Furthermore, mulch control weeds growth which would have competed with crops for water and nutrient uptake resulting to high biomass accumulation (Pande *et al*., 2005; Singh *et al*., 2008). Biomass accumulation varies from a variety to another, this is due to the genomic makeup of the varieties with others having more branches than others and the size in terms of height.

2.8.2 Biomass partitioning in green gram

Efficient partitioning of biomass into yield is represented by harvest index (Chauhan *et al*., 2018). Green gram harvest index is 0.3 which is low compared to soybean and peanut which is about 0.5 (Thomas *et al*., 2004). Attempts to improve harvest index in green gram has not been successful although being regarded as a major constraint to achieving high grain production. Major improvement target must be on crops with harvest index (HI) less than 0.5 (Hay *et al*., 1995). Harvest index increase is not constant for entire seed growth period but linear and statistically suitable when harvest index increased from 10-90% of its maximum value (Bindi *et al*., 1999).

The idea that yield-based selection will indirectly select for increased HI may not be valid, but longer crop period or better vegetation growth instead of HI may increase yield obtained as a result of increased production of dry matter in yield-based selection (Chauhan *et al*., 2018). The low HI in green gram suggests there could be great potential for improvement (Chauhan *et al*., 2018). The phenology of the crop interacts with the growth habits to determine crop period in influencing the partitioning of dry matter (Lawn *et al*., 1982). In green gram, the flowering is less concurrent under prolonged crop period. The lack of flowering harmony in green gram is the main contributor to low harvest index, which result from day length being longer than that of the critical photoperiod (Bushby and Lawn, 1992). Therefore, the critical photoperiod for appropriate partitioning might be different from that for flowering (Chauhan *et al*., 2018).

CHAPTER THREE: DETERMINATION OF THE EFFECT OF METHOD TILLAGE AND APPLICATION OF MULCH ON CROP GROWTH, NODULATION AND YIELD OF GREEN GRAMS

3.1 Abstract

Conservation tillage plays significant roles as the most appropriate practice in production of crops in the dry lands. Nevertheless, tillage and mulch have no sufficient documentation of its effects on green gram yield in semi-arid parts of Kenya. A field experiment was performed during the short rains of 2018-2019 in Katumani and Mwea. The experiment had three replicates in a split-split plot arrangement where a randomized complete block design (RCBD) was used. Zero tillage (ZT), conventional tillage (CT) and furrow-ridge (FR) were the three main tillage systems that composed the main plots. The split plots were no mulch (0 t ha^{-1} (control) and mulched 3 t ha^{-1}), while in the split-split plots contained variety N26 and KS20 of green gram. Data collected for percentage (%) emergence, days to 50% flowering, 75% maturity, plantheight, number of primary branches, nodules and their dry weight, root and shoot biomass, number of pods plant, number of seeds per pod, grain weight and harvest index. Separation of mean was performed using least significant difference (LSD) at 5 % probability level. Analyzed data revealed that methods of tillage and application of mulch had significant effect on crop phenology, plant growth parameters, yield and its component. Out of the three methods of tillage, furrow-ridge had greater impact on the two varieties of green grams along its physiological stages with conventional tillage recording the least. Mulch significantly affected crop phenology, plant development, yield and its components. KS20 planted in furrow-ridge mulched with 3 t ha^{-1} of plant residue had more nodules compared to variety N26. Furthermore, variety N26 under similar treatment recorded more numbers of branches, plant height, yield and its components in Katumani and Mwea. Mulch application significantly affected growth, yield and its component. The tillage method that produced the most suitable techniques to produce green gram in Katumani and Mwea were furrow-ridge and zero tillage. With these findings' recommendation could be drawn suggesting furrow-ridge and zero tillage as the suitable practices with mulch to conserve moisture which plays crucial roles in crop yield.

Key words: furrow-ridge, zero tillage, phenology, growth, yield and yield components

3.2 Introduction

Low crop production in ASALs is due to less and unevenly distributed rainfall during the cropping season (Kwena *et al*., 2018; Karuma *et al*., 2016). The semi-arid lands in Kenya experiences more evapotranspiration between 2000–2300mm per annum (Kisaka *et al.*, 2015). The soil in the semi-arid is constraint by low and poor physical firmness which allow them easily eroded and with low macro and micronutrients (Kinama *et al*., 2005). Moisture conservation through better tillage practices plays important role for crop production in arid and semi-arid areas (Karuma *et al.*, 2016). Thus, under normal condition, conservation tillage scale up yield by 4.6% (Chen *et al*., 2014).

Zero tillage, furrow-ridge and mulch application play important role in soil moisture conservationand nutrient recycling (Verhulst *et al*., 2010; Johnson *et al*., 2018). Zero tillage and furrow-ridge were reported to increase yield as a result of moisture conservation and nutrient availability (Micheni *et al*., 2014). Zero tillage reduce surface runoff which increases soil water infiltration and increasessoil organic matter (Busari *et al.*, 2015). Furrow-ridge plays important role in moisture conservation and efficient use of fertilizers as the shape of the ridge prevent nutrient from leaching (Kristensen and Sorensen, 2013). Application of mulch and effective mulching techniques increasecrop yield and water use efficiency (Chen and Feng, 2013; Memon *et al*., 2017).

The use of mulching materials has shown to reduce soil erosion, allowing increased water infiltration (Bhardwaj, 2013). Siipilehto (2001) and Laurie *et al.* (2015) reported reduced effect of weeds on growth and yield of crops with mulch application. Applicationof mulch in a field has significant importance on the hydro-physical properties of soil for example soil organic matter (SOM), field capacity, bulk density of soil, porosity (Kakaire *et al.*, 2015). Mulching enhances both macro and micronutrients to the soil (Shahid *et al*., 2014). Mulch application also regulates soil temperature and this promotes soil microbial activities and soil moisture conservation (Kinama, 1997; Li *et al.*, 2001; Gan *et a*l., 2013). Crop productivity is improved as a result of the use of conservation tillage techniques like furrow-ridge, no till and together with mulch application. However, there has been few studies conducted to understand use of improved tillage method in increasing the productivity of green gram.

3.3 Materials and methods

3.3.1 Experimental sites

These experimental studies were carried out at Kenya Agricultural and Livestock Research Organization (KALRO) based in Katumani of Machakos County and Mwea of Kirinyaga County during 2018/2019 short rains season. KALRO Katumani is located on 01° 35' S, 37° 14' E with an elevation of 1600 m above the sea level. The two sites experience two rainy seasons. The long rains season is experienced from March to June and short rains season falls from October to January (Jaetzold *et al*., 2006). The average rainfall for long time shows 309.9 mm and 450 mm for the long rains in Katumani and Mwea, respectively (Huho and Mugalavai, 2010). Temperature ranges from 17 and 24°C and mean annual water loss is between 1820 mm and 1840 mm (Gicheru and Ita, 1987). Soils of this site is deep to very deep, well drained, dark red to reddish brown, weakly structured and friable Luvisols soils with low organic carbon (Jaetzold *et al*., 2006).

The research Centre in Mwea is on 37' S 37 20' E, at an altitude range of 1159 m above the level of sea in Kirinyaga County. Mwea receives two rainy seasons with an annual mean rainfall of 850 mm. Temperature range is 15.6 - 28.6°C and mean of 22°C.

3.3.2 Experimental layout, design, and treatments

The experiment comprises of six (6) treatments; furrow-ridge, zero tillage and conventional tillage mulched with 3 t ha^{-1} of plant residue and same tillage without mulch applied. Variety N26 and KS20 of green gram were used to conduct the experiment in each of the treatment. A randomized complete block design (RCBD) with a split-split plot layout was used for the treatment. Tillage method as the main plot, plant residue applied as mulch to cover the sub plot and finally the two green gram varieties N26 and KS20 covering the sub-sub plot with three replicates for each treatment. The sub-sub plot covers a length of 5 m and a width measuring 2.25 m and the experimental area used to conduct this research study was 760.5 m^2 and a space of 2 m was left in between blocks and 1 m separating plots apart. The tillage methods in the main plots are zero, furrow-ridge and conventional tillage while the split plots contained mulched plots with plant reside and those plots without mulch applied. The last portion which is the split -split plot contained green gram variety N26 and KS20 which were breed for drought tolerance from Kenya Agricultural and Livestock Research Organization (KALRO) in Katumani.

3.3.3 Experiment management

The land in conventional tillage was tilled using hoe to a proper seed bed that could allow direct seeding during sowing of the green gram seeds. For plots in zero tillage preparation of seedbed was done through cutting the grasses and weeds to ground level later herbicide Dual Gold 960 EC at 4 liters/ ha was applied to destroy the weeds a fortnight before sowing was done minus soil disturbance. Hills were heaped to 20 cm high and spaced at 45 cm in between rows of the hills under furrow ridge. Analysis to determine soil nutrient requirement was conducted at National agricultural research Laboratories (NARL) for samples from both Katumani and Mwea. Application of fertilizer was done in regards to results from the analysis and recommendation for nutrient application for the two sites. Results from the analysis recommended fertilizer addition of 140 kg/acre of N: P: K 17:17:17 in Mwea and 2 tons addition a properly decomposed cow manure. Katumani experimental site was recommended addition of 4 tons of a properly decomposed cow manure. To ensure uniformity, three green gram seeds were sown per hole and later thinned to one plant per station at a space of 20 cm between plants and 45 cm in between rows at 4cm depth. Application of the 3t ha^{-1} of mulch was done after planting in plots with mulch. ABSOLUTE 375SC 10ml/20L was used to control powdery mildew and TRACER 480SC with active Spinosad ingredients was used to control common pest such as thrips through spraying.

3.4 Data collection

3.4.1 Weather data

Data collected on meteorological conditions included precipitations (mm), temperature (^{o} C) plus humidity (%) monthly from KALRO Katumani which was 200 m from the weather station and 500 m forMwea weather stations

3.4.2 Soil sampling and analysis

Prior to sowing, soil samples from the two study sites; Katumani and Mwea were collected usingsoil auger from 0–15 and 15-30 cm soil depths. These depths were informed by the fact that greengram roots mainly concentrate in the 0-30 cm depth and hardly go beyond 15 cm depth at pre- flowering stage. Sampling was done randomly in a zig-zag pattern. The samples were compositedin a container and a sub-sample of about 1 kg transported to the laboratory for chemical analysis.The samples were air dried, passed through a 2 mm sieve for analysis of soil pH, Nitrogen, OrganicCarbon, phosphorus, calcium, Magnesium, Manganese, copper and Iron using standard laboratoryprocedures as described by Okalebo *et al*. (2002).

Soil pH was analyzed using 1:2.5 soil to water suspension with pH-meter (Mechlich *et al*, 1962). Total nitrogen was determined using Kjeldahl digestion method (Page *et al*, 1982). Total organic carbon was examined using calorimetric method (Anderson and Ingram, 1993). Potassium, Phosphorus, Magnesium and Calcium were tested using Mehlich double acid method (Mehlich *etal*., 1962). Potassium was examined by means of flame photometer while phosphorus was tested using calorimetric method. Micronutrients were examined using Atomic Absorption Spectrophotometer (AAS) method.

3.4.3 Phenology

Data on % emergence was done by counting number of holes that plant emerged from in a plot measuring 5 m × 2.5 m with 150 plant holes. Three (3) seeds were sown per hill and later thinned to one plantper station. The holes with emerged plant were counted then percentage recorded from the 150 expected plants. Data on days to 50 % of plants flowering was done by counting the number of days taken by 50% of the plants to flower and to reach 75 % maturity in Katumani and Mwea.

3.4.4 Growth parameters

Plant height was taken from 5 randomly selected green gram plants at two different growth stages;vegetative (30 days after sowing) and flowering (45 days after sowing) from each plot under eachtreatment using a meter rule and average height recorded.
Number of primary branches was taken by counting the branches from five plants selected randomly in each plot under each treatment at harvest.

Number of nodules was taken by destructive sampling from 5 plants at vegetative and flowering stages. Before uprooting, the selected plants were watered at the base of the soil for easy removaland avoid stripping off of nodules. The uprooted plants were cut to separate the above ground biomass. The roots were washed with clean water and nodules separated by plucking and counting.Nodules dry weights at vegetative and flowering stages were determined after nodules were put inseparate kaki bags and oven dried at 70^0C for 24 hours. Nodule dry weight was determined by averaging the dry weight in grams.

Five Plants were randomly sampled at flowering and matured stage of green gram to collect data on root biomass. This was done by watering the surface of the soil and the plant pulled gently out of the soil with all the roots then cut at base of the stem. To get the exact plant roots weight, the cut part of the root is put in an oven to dry for 48 hours at a temperature of 70°C until dry weight is achieved. Root biomass data is then collected from the dry weight of the 5 sampled plants and weight recorded in tons per hectare.

3.4.5 Yield and yield components

An average number of pods was recorded after a number of five plants were selected on a random basis to determine pods number per plant in each experimental plots from both experimental sites.

Seeds numbers per pod was calculated by randomly selecting 10 green gram pods under every plot then pods threshed and average recorded after a count from the 10 pods.

Following pod threshing and winnowing, 1000 seeds were counted at random and weight of 1000 seeds were recorded after an electric weighing scale balance was used to determine their weight.

Data on the yield of green gram per hectare (t ha^{-1}) was recorded harvest was done from an area covering 4.2 m × 1.35 m from each experimental treatment after which pods were softly threshed cleaned and weight taken in tons per hectare.

For harvest index, grain yield of green gram in t ha^{-1} and green gram biomass yield t ha^{-1} taken from the research sites (Eqn 1).

$$\text{Harvest index} = \frac{\text{Grain yield (kilo gram per hectear)}}{\text{Total dry weight (kilo gram per hecte)}} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{(1)}$$

3.5 Statistical analysis

GenStat 15th statistical software was used to conduct the general analysis of variance for all collected data on plant phenology, growth, yield its components and were subjected to general analysis of variance using. Separation of mean was gotten through the use of least significant difference LSD at 5% probability.

3.6 Results

3.6.1 Weather data during the season

Precipitation in whole of Machakos County where Katumani is located and in Kirinyaga where Mwea is situated has always been below to support good crop yield with an average rainfall of 294.2 mm and 327 mm (Table 3.1). The precipitation experienced between 2018/2029 2018/2019 wasn't enough in the two sites with Mwea recording the lowest mean monthly rainfall of 39.7mm and Katumani 101.1mm. Rain started in Mid-October 2018 with the highest rainfall was in December in Katumani and in November in Mwea. The lowest amount of precipitation recorded in January in both experimental sites and the highest average monthly temperatures recorded was 29.8 ^{O}C in Mwea than in Katumani with relative humidity at was 76.03% in Mwea and 59.5% in Katumani respectively

Table 3. 1: Rainfall. Temperature and relative humidity of the two study sites (Mwea and Katumani)

	Katumani			Mwea		
Months	R (mm)	T(^{O}C)	H (%)	R(mm)	T (^{O}C)	H (%)
October	23.5	20.2	59.5	23.6	22.7	64.19
November	150.0	20.2	67.5	79.3	22.2	72.17
December	214.8	19.5	77	45.4	21.7	76.03
January	16.8	19.4	69	10.5	29.8	66.56

R= rainfall, T= temperature and H = humidity

3.6.2 Experimental sites soil characterization

Table 3.2 presents soil physical and chemical properties before sowing in Katumani and Mwea during the short rains of 2018/2019. In Katumani, soil pH was slightly acidic, though within the range suitable for crop production. The soil organic carbon was very low as anticipated under hightemperature conditions and in sandy soils where organic matter decomposes rapidly (Feller and Beare, 1997). This was an indication of poor soil structure and low soil water holding capacity. The total nitrogen content was limiting and could not achieve the maximum green gram yield. Potassium and phosphorus levels were adequate though regular applications of organic inputs to replenish the removed nutrients through crop harvest and leaching is necessary. The micro and macro nutrients were in adequate amounts for optimal production based on the rating by London *et al*. (2014). In Mwea soil pH was satisfactory for crops' growth. Nitrogen, phosphorus, potassium was deficient in the soil and was improved by application of

NPK 17:17:17 fertilizer at 140 kg/acre plus addition of 2 tons of properly decomposed cattle manure. In Katumani soil organic matter was moderate and was improved by application of 4 tons of well decomposed cow manure along the ridges and line of planting.

3.6.3 Effect of tillage method and mulch application on crop phenology

The analyzed data reported that crop emergence varied significantly ($P \leq 0.05$) with tillage methodsin the two sites. Emergence was higher in furrow-ridge, followed by conventional tillage andlater in zero-tillage) (Table 3.3).

Table 3. 2: Baseline soil physical and chemical properties in Katumani and Mwea

KALRO Katumani			KALRO Mwea	
Fertility results	value	class	value	Class
Soil Ph	6.36	slight acid	5.85	medium acid
Total Nitrogen %	0.1	low	0.13	Low
Total Organic Carbon %	0.82	low	1.45	Moderate
Phosphorus ppm	150	high	15	Low
Potassium ppm	84	Suitable	35	Low
Calcium me%	6.6	Suitable	2.6	Suitable
Magnesium me%	4.81	high	1	Suitable
Manganese me%	0.31	Suitable	0.46	Suitable
Copper ppm	1.5	Suitable	1.33	Suitable
Iron ppm	14.3	Suitable	16.6	Suitable
Sodium me%	0.4	Suitable	0.12	Suitable

(Rating of nutrients was based on the standards provided by Landon *et al*. (2014)

Emergence was not significantly ($P \geq 0.05$) affected by the application 3 t ha^{-1} mulching materials,varieties, and interactions. Tillage method did not significantly ($P > 0.05$) affect days to 50% flowering in both study sites. However, application of plant residues at 3 t ha^{-1} significantly ($P \leq 0.05$) influenced days to 50% flowering. Crops in mulched plots delayed to flower in Katumani and Mwea compared to those in un-mulched plots.

Number of days taken by the crops to reach 50% flowering was significantly ($P < 0.001$) affected by variety. Variety KS20 reached 50% flowering 13 and 12 days earlier compared to N26 in Katumani and Mwea respectively. The interactions of tillage, mulch and variety did not significantly affect day to 50% flowering in both sites.

Days to 75% physiological maturity was significantly ($P \leq 0.05$) affected by tillage method in both sites. Crops in conventional tillage took 4 and 3 days earlier to reach 75% maturity compared to furrow-ridge and zero tillage in the two sites respectively (Table 4.3). Mulch application significantly ($P < 0.001$) affected days to 75% maturity. Application of 3t ha^{-1} extended days to 75% physiological maturity more than in un-mulched plots in Katumani and Mwea respectively. Days to 75% physiological maturity varied significantly ($P < 0.001$) with variety in both sites. Variety KS20 took fewer days to reach 75% physiological maturity compared to variety N26.

The interaction between tillage × mulch significantly affected days to 75% physiological maturity in Katumani but didn't have effect in Mwea. However, tillage × variety, mulch × interaction between variety and tillage × mulch × variety had no significant effect on days to 75% physiological maturity.

Table 3. 3: Emergence %, days to 50% flowering and days to 75% maturity in Katumaniand Mwea

Tillage	Katumani			Mwea		
	(%) Emergence	50% Flowering	75% Maturity	(%) Emergence	50% Flowering	75% Maturity
Conventional tillage	96b	45a	72b	98a	46a	72b
Furrow-ridge	98a	46a	75a	99a	46a	74a
Zero tillage	96b	46a	76a	96b	46a	75a
LSD	1.28	1.91	2.33	1.13	1.96	1.28
P Value	0.021	0.226	0.022	0.003	0.866	0.009
Mulch						
0 t/ha	97a	44b	73b	97a	44b	73b
3 t/ha	97a	48a	76a	97a	48a	75a
LSD	1.83	1.03	0.80	0.38	3.55	1.16
P Value	0.96	<.001	<.001	0.205	0.026	0.004
Variety						
KS20	96a	40b	63b	97a	40a	84a
N26	97a	53a	85a	97a	52b	64b
LSD	1.84	1.09	1.12	0.27	1.94	1.13
P Value	0.42	<.001	<.001	0.336	<.001	<.001
Interactions						
Tillage × Mulch	0.44	0.37	0.01	0.25	0.61	0.41
Tillage × Variety	0.06	0.63	0.14	0.17	0.67	0.11
Mulch × Variety	0.89	0.25	0.26	0.54	0.95	0.31
Tillage× Mulch × Variety	0.71	0.85	0.99	0.09	0.18	0.50

LSD is least significant difference; means followed by same letter are not significantly at P ≤0.05

3.6.4 Tillage methods and mulch application on crop growth traits

Tillage method significantly affected the height of the plants at both vegetative and flowering stages and number of branches as indicated in (Table 3.4). Furrow-ridge recorded higher at (44.04 cm) followed by (39.21cm) under conventional land tillage practices and least in the category was zero tillage with (37.81cm), respectively.

Application of mulch significantly ($P \leq 0.05$) affected plant height in Katumani and Mwea. Plots with 3 t ha^{-1} of plant residue applied were (5.4 cm) and (4.5 cm) taller than those grown under no- mulch in Katumani and Mwea, respectively.

There was no significant ($P \geq 0.05$) effect of variety on plant height at both vegetative and flowering stages. Interactions had no significant ($P \geq 0.05$) effect on plant height at the vegetative stage in both sites. At flowering stage there was significant ($P \leq 0.001$) effect of interaction between tillageand mulch. Maximum plant height was observed in furrow-ridge plots compared to those under conventional and zero tillage mulched same 3 t ha $^{-1}$ of plant residues.

Table 3. 4: Crop height at vegetative, flowering stages and number of crop branches in Katumani and Mwea

Treatments + interactions	Katumani			Mwea		
	CHV	CHF	NB	CHV	CHF	NB
Tillage						
Conventional tillage	39.21b	49.92b	4b	32.79b	47.33b	3.00a
Furrow-ridge	44.04a	60.35a	5a	36.76a	55.18a	3.00a
Zero tillage	37.81b	47.50c	4b	30.95b	39.70c	4.00a
LSD	3.35	1.88	0.19	2.77	4.25	0.65
P-value	0.014	<.001	0.005	0.01	0.001	0.529
Mulch						
0 t/ha	37.65b	58.69b	4.00b	31.26b	44.02b	4.00b
3 t/ha	43.06a	66.77a	5.00a	35.74a	50.79a	5.00a
LSD	0.67	0.84	0.33	1.38	3.00	0.49
P-value	0.014	<.001	0.004	<.001	0.001	0.008
Variety						
KS20	40.50a	65.13a	4.00b	33.85a	49.23a	3.00b
N26	40.21a	60.33b	5.00a	33.15a	45.58b	5.00a
LSD	0.62	0.78	0.17	0.78	0.78	0.30
P-value	0.319	<.001	<.001	0.075	<.001	<.001
Interactions						
Tillage × Mulch	0.014	0.003	0.373	0.196	0.446	0.609
Tillage × Variety	0.338	0.020	0.262	0.564	0.917	0.848
Mulch × Variety	0.834	0.242	0.493	0.490	0.762	1.000
Tillage × Mulch × Variety	0.123	0.248	0.001	0.950	0.293	0.619

CHV is height of crop at vegetative, CHF= height of crop at flowering, NB= No. of branches LSD is least significant difference and means followed by the similar alphabets are not different significantly at $P \leq 0.05$.

Number of branches varied significantly ($P \leq 0.005$) with tillage methods in Katumani but not observed in Mwea. Green grams grown under furrow-ridge recorded a greater number of branches compared to those under conventional and zero-tillage. Application of mulch significantly influenced number of branches in both Katumani and Mwea. Plots mulched with 3 t ha^{-1} of plant residues recorded a greater number of branches compared to those without mulch applied. the number of branches in both sites.

Variety had significant ($P < 0.001$) effect on the number of branches in the two experimental sites of Mwea and Katumani. Variety N26 recorded a greater number of branches as opposed to variety KS20 (Table 3.4).

3.6.5 Effects of tillage methods and mulch on root biomass at flowering and maturity

The biomass of roots recorded at the two growth stages (flowering and maturity) were significantly ($P \leq 0.05$) impacted by tillage and applied 3 t ha^{-1} plant residue mulch. Root biomass recorded under furrow-ridge was higher than rootbiomass under conventional and zero-tillage in both sites. A similar trend was observed at crop maturity stage. Furrow-ridge recorded superior root biomass compared to conventional tillage andzero tillage. It was also noted that addition of mulch significantly ($P < 0.001$) influenced the root biomass.

Plots with 3 t ha^{-1} of plant residue applied recorded high biomass of green gram roots compared to the ones without mulch applied. There was no significant ($P = 0.343$) effect of variety on biomass of green gram recorded with the N26 and KS20 green gram varieties (Table 3.5).

The interactions between tillage × variety, mulch × variety and tillage × mulch tillage × variety at flowering and maturity had no significant effect on green gram root biomass in both sites however, tillage × mulch interaction has significantly affected root biomass in Katumani.

Table 3. 5: Root biomass of green gram under contrasting tillage method and mulch in Katumani and Mwea

Treatments + interactions	Katumani Flowering	Maturity	Mwea Flowering	Maturity
Tillage method				
Conventional tillage	1.92b	3.72b	1.59b	3.60b
Furrow-ridge	2.59a	4.50a	1.88a	3.98a
Zero tillage	2.03b	3.21c	1.56b	3.45b
LSD	0.25	0.37	0.214	0.36
P-value	0.004	0.001	0.03	0.033
Mulch				
0 t/ha mulch	1.69b	3.38b	1.32b	3.30b
3 t/ha mulch	2.67a	4.30a	2.03a	4.06a
LSD	0.10	0.41	0.11	0.22
P-value	<.001	0.001	<.001	<.001
Variety				
KS20	2.16a	3.83a	1.67a	3.66a
N26	2.20a	3.85a	1.69a	3.70a
LSD	0.08	0.10	0.25	0.05
P-value	0.343	0.787	0.133	0.158
Interactions				
Tillage × Mulch	0.003	0.144	0.283	0.348
Tillage × Variety	0.798	0.927	0.475	0.493
Mulch × Variety	0.072	0.991	0.096	0.929
Tillage × Mulch × Variety	0.377	0.647	0.696	0.072

LSD is least significant difference; means followed by the same letter are not significantly differentat $P \leq 0.05$

3.6.6 Tillage methods and mulch on nodulation

Table 3.5 presents data on number of nodules and nodules dry weight at vegetative and floweringstages of green gram. Tillage and mulch application had significant ($P = 0.01$) impact on nodulation at vegetative and flowering stages. Higher numbers of nodules and nodules dry weight were recorded in furrow- ridge in both sites compared to zero and conventional tillage (Table 3.5).

Application of mulch significantly ($P \leq 0.05$) affected number of nodules in Katumani and Mwea. Applied 3 t ha^{-1} of plant residue increased root nodules in Katumani and Mwea compared to plots without mulch and similar trends were observed on nodules dry weight.
Number of nodules and nodule dry weight varied significantly ($P < 0.001$) with variety. Variety KS20 recorded higher number of nodules than variety N26 in both sites. A similar trend was noted onnodule dry weight.

Interaction of tillage × mulch × varieties had significant effects on number of nodules at floweringstage. Nodules mass at vegetative varied significantly with mulch ($P \leq 0.05$). High nodule dry weight was recorded in plots following the application of 3 t ha^{-1} of plant residue as opposed to plots not mulched.

Table 3. 6: Number of nodules and nodule dry weight at different growth stages in Katumaniand Mwea

Treatment + interactions	Katumani				Mwea			
	NNV	NNF	NBV	NBF	NNV	NNF	NBV	NBF
Tillage method								
Conventional tillage	12.00b	19.00b	0.03b	0.05a	12.00b	16.00b	0.031b	0.042a
Furrow-ridge	15.00a	24.00a	0.04a	0.05a	14.00a	19.00a	0.035a	0.045a
Zero tillage	12.00b	16.00c	0.03b	0.04b	10.00c	14.00c	0.027b	0.037b
LSD	1.110	1.903	0.004	0.002	1.917	1.731	0.003	0.003
P-Value	0.007	<.001	0.046	<.001	0.008	0.003	0.005	0.006
Mulch								
0 t/ha	16.78b	11.67b	0.029b	0.04b	10.83b	15.00b	0.029b	0.038b
3 t/ha	21.83a	14.50a	0.034a	0.05a	13.28a	18.00a	0.0333a	0.046a
LSD	0.451	1.676	0.002	0.002	0.745	1.714	0.002	0.003
P-Value	<.001	<.001	0.002	<.001	<.001	0.004	<.001	<.001
Variety								
KS20	15a	23a	0.034b	0.05a	13a	18.00a	0.0331a	0.045a
N26	11b	16b	0.029a	0.04b	11b	15.00b	0.0286b	0.038b
LSD	1.180	0.794	0.001	0.001	0.484	2.054	0.001	0.003
P-Value	<.001	<.001	<.001	<.001	<.001	0.012	<.001	<.001
Interactions								
Tillage × mulch	0.770	0.007	0.770	0.228	0.412	0.034	0.87	0.834
Tillage × variety	0.574	0.002	0.574	<.001	0.584	0.041	0.55	0.688
Mulch × variety	0.655	0.002	0.655	0.002	0.159	0.001	0.275	0.133
Tillage× mulch × variety	0.270	0.003	0.988	0.034	0.061	0.051	0.168	0.172

Legend: NNF = nodules at flowering, NBV= nodules biomass at vegetative, NBF= nodules biomass at flowering and means followed by the same letter are not significantly different at $P \leq 0.05$

Variety significantly ($P \geq 0.05$) affected nodule dry weight in both Katumani and Mwea. Variety KS20 recorded higher nodule dry weight compared to variety N26. The number of nodules and nodule dry weight was not significantly affected by tillage, mulch and variety interactions at vegetative. However, at flowering the interaction between tillage, mulch and variety significantlyaffected the number of nodules. Nodules dry weight varied significantly between tillage × variety, mulch × variety and tillage × mulch × variety interaction while tillage and mulch interaction didn’t have significant effect in Katumani.

3.6.7 Effects of tillage method and mulch application on yield and yield components

The result from the analysis has shown that tillage and mulching significantly ($P \leq 0.05$) impacted pods number per plant in both experimental sites (Table 3.6). There were more pods (61) recorded under furrow-ridge and (48 pods) under zero-tillage with the lowest under conventional tillage (41 pods). The same trend pods number per plant was recorded in Mwea experimental site (44, 40 and 38 pods), respectively.

Addition of mulch significantly ($P \leq 0.05$) affected number of pods per plant in Katumani and Mwea. Plots with 3 t ha^{-1} application of plant residue produced more pods compared to those treatments without mulch. It was also noted that the number of pods per plant varied significantly ($P <0.001$) with variety. Variety N26 recoded 53 pods, significantly higher 47 pods recorded in the KS20 variety. In Katumani, the number of pods per plant was significantly ($P = 0.03$) affected by the interactions between tillage and variety. More pods were recorded in variety N26 under furrow-ridge and least in KS20 under conventional tillageand similar trend was recorded in Mwea. No significant effect was recorded between interactions in Katumani, but in Mwea pods number per plant was significantly ($P = 0.01$) affected by the interaction between mulch and variety. Variety N26 under plots mulched with plant residue of 3 t ha^{-1} of had more pod numbers per plant and the least was variety KS20 in plots not mulched.
There wasn't any significant effect from the interactions between tillage × variety, tillage × and tillage × mulch ×variety on the number of pods per plant.
Grain yield in the two experimental sites was significantly ($P < 0.001$) affected by type of tillage and application of mulch. high yield of green gram grain (1.09 t ha^{-1}) was under furrow-ridge and the second highest yield was under zero-tillage (1.01 t ha^{-1}) with the lowest green gram grain yield was (0.93 t ha^{-1}) under conventional tillage in Katumani and similar green gram yield trends also in Mwea. Mulch significantly ($P \leq 0.05$) impacted yield and biomass in Katumani and Mwea. Plots with 3 t ha^{-1} of plant residue mulch applied had high grain yield of (0.14 t ha^{-1} and 0.16 t ha^{-1}) than plots with no mulch applied in the two experimental sites of Katumani and Mwea.

Variety significantly ($P \leq 0.05$) affected grain yield and biomass at harvest in both Katumani and Mwea. High grain yield was recorded with variety N26 of 0.13 t ha^{-1} and 0.1 t ha^{-1} from the two sites compared to KS20 variety.

Table 3. 7: Pods number per plant, seeds number per pod and thousand (1000) seeds weight under different tillage method and mulch in Katumani and Mwea

Treatments + Interactions	Katumani			Mwea		
	NPP	NSP	TSW	NPP	NSP	TSW
Conventional tillage	41c	13a	55.54c	38c	13a	64.00a
Furrow-ridge	61a	13a	71.35a	44a	13 a	69.00a
Zero tillage	48b	13a	60.32b	40b	13 a	64.92a
LSD	1.51	0.87	1.91	1.89	1.28	5.06
P-value	<.001	0.678	<.001	0.002	0.864	0.102
Mulch						
0 t/ha	46b	13a	60.48b	37b	13a	63.11b
3 t/ha	54a	13a	64.33a	44a	13a	68.33a
LSD	2.04	0.19	1.75	1.56	0.24	2.39
P-value	<.001	1.00	0.002	<.001	0.06	0.003
Variety						
KS20	47b	13b	63.89a	36b	13b	68.83a
N26	53a	14a	60.92b	45a	14a	63.11b
LSD	2.01	0.17	0.80	1.33	0.24	1.28
P-value	<.001	<.001	<.001	<.001	<.001	<.001
Interactions						
Tillage × Mulch	0.55	0.3	0.86	0.54	0.73	1.00
Tillage ×Variety	0.03	0.62	0.74	0.43	0.22	0.89
Mulch ×Variety	0.25	1.00	0.19	0.01	0.34	0.78
Tillage × Mulch × Variety	0.54	0.26	0.83	0.38	0.78	0.05

NPP= number of pods per plant, NSP= number of seeds per pod, TSW= thousand seed weight and means followed by same letter are not significantly different at P ≤0.05.

The interaction between tillage × variety, mulch × variety and tillage × mulch × variety had significant (P ≤ 0.05) effect on grain yield but the interaction between tillage × mulch did not significant effect on grain yield in Katumani. In Mwea, no significant interactions were reported. Shoot biomass at flowering varied significantly (P ≤ 0.05) with tillage in both Katumani and Mwea. High shoot biomass was under furrow-ridge than in zero tillage conventional tillage. Mulch application had significant (P ≤ 0.05) effect on biomass at flowering stage in both sites. Plots mulched with 3 t ha $^{-1}$ recorded more biomass compared to biomass yielded at flowering stage in plots without mulch. There was significant (P ≤ 0.05) effect of variety on biomass in both Katumani and Mwea. VarietyN26 recorded a high shoot biomass compared to KS20 (Table 3.6).

Tillage × mulch interaction didn't significantly affect shoot biomass in both sites at flowering stage. However, the interaction between tillage × variety and mulch × variety significantly effected shoot biomass.

Furthermore, tillage × mulch × varieties interaction significantly ($P \leq 0.05$) impacted shoot biomass at flowering in Katumani, though it didn't have similar effect in Mwea. Tillage and mulch significantly ($P \leq 0.05$) impacted biomass at harvest in both Mwea and Katumani. High plant biomass was registered under furrow-ridge with (3.63 t ha^{-1}) then in zero tillage with (3.22 t $ha^{-1)}$ and finally (3.13 t ha^{-1}) under conventional tillage in Katumani and Mwea with similar trends.

Application of mulch significantly ($P \leq 0.05$) affected biomass at harvest in both Katumani and Mwea. Application of 3 t ha^{-1} of mulch increased green gram plant biomass by 0.52 t ha^{-1}) in Katumani experimental site and (0.59 t ha^{-1}) in the experimental site of Mwea. Varietal difference had a significant ($P < 0.001$) effect on plant biomass at harvest in both experimental site of Katumani and Mwea. Variety N26 recorded High biomass (0.46 t ha^{-1}) was yielded by variety N26 in Katumani experimental site and (0.37 t ha^{-1}) in Mwea experimental site compared to biomass yielded by variety K20. The interaction between tillage × mulch and tillage × mulch × variety had significant ($P \leq 0.05$) effects on green gram biomass however, the interaction between tillage × variety and mulch × variety had no significant impact on green gram biomass in Katumani. While in Mwea there was no significant effect of interaction on green gram biomass at harvest.

Tillage types and applied mulch didn't have significant effect on green harvest index both Mwea and Katumani experimental sites. However, there was significant ($P = 0.03$) effect of tillage × mulch× variety interaction on green gram harvest index in Katumani though no effect was analyzed in Mwea (Table 3.6). High harvest index of (35%) was recorded by variety KS20 under zero-tillage without mulch applied and the lowest was under conventional tillage with 3 t ha^{-1} of plant residue mulch applied. Generally, high harvest index was with variety KS20 compared to variety N26.

Table 3. 8: Shoot biomass, grain yield and harvest index under contrasting tillage methods and mulch in Katumani and Mwea

Treatments + Interactions	Katumani BF	BH	Y	HI	Mwea BF	BH	Y	HI
	($t\ ha^{-1}$)	($t\ ha^{-1}$)	($t\ ha^{-1}$)	(%)	($t\ ha^{-1}$)	($t\ ha^{-1}$)	($t\ ha^{-1}$)	(%)
Conventional tillage	3.8c	3.13b	0.93c	30	3.6b	3.0b	0.91b	31
Furrow-ridge	4.6a	3.63a	1.09a	30	3.9a	3.5a	0.96a	27
Zero tillage	4.1b	3.22b	1.01b	31	3.7ab	3.0b	0.92ab	31
LSD	13.3	0.19	0.03	0.02	32.7	0.17	0.05	0.03
P-value	<.001	0.004	<.001	0.125	0.043	0.002	0.044	0.04
Mulch								
0 t/ha	3.8b	3.1b	0.94b	31	3.4b	2.9b	0.85b	30
3 t/ha	4.5a	3.6a	1.08a	30	4.0a	3.5a	1.01a	29
LSD	11.17	0.29	0.03	0.03	19.16	0.21	0.05	0.03
P-value	<.001	0.005	<.001	0.453	<.001	<.001	<.001	0.77
Variety								
KS20	3.9b	3.1b	0.9b	31	354b	3.0b	0.91b	30
N26	4.4a	3.6a	1.1a	30	392a	3.4a	1.01a	30
LSD	8.32	0.12	0.02	0.01	8.02	0.13	0.05	0.02
P-value	<.001	<.001	<.001	0.371	<.001	<.001	<.001	0.51
P values for interactions								
Tillage × Mulch	0.19	0.01	0.19	0.43	0.97	0.31	0.57	0.46
Tillage × Variety	0.05	0.38	0.02	0.08	0.03	0.83	0.23	0.28
Mulch × Variety	0.03	0.09	0.01	0.24	0.01	0.19	0.38	0.93
Tillage. Mulch. Variety	0.02	0.05	0.04	0.03	0.11	0.21	0.56	0.79

LSD is least significant difference; BF= biomass at flowering, BH= biomass at physiological maturity, Y= grain yield, HI= harvest index and means accompanied by same alphabetic letters are not having significant difference at $P \leq 0.05$.

3.7 Discussion

3.7.1 Tillage methods and mulch on crop phenology

Tillage methods and mulch applied mulch had significant effect on crop emergence was recorded in Katumani and Mwea. Crops emerged earlier in furrow ridge and conventional tillage compared to zero tillage. The emergence of crops greatly depends on the tillage techniques as supported by Yadav *et al.* (1995). In the zero tillage, the crops delayed emerging probably due to surface sealing and soil compaction effect. The result concurs with the findings of Su-Juan *et al.* (2008) who found out that delayed time of seedling emergence in zero tillage as compared to conventional and minimum tillage due to soil compaction. This observation is also in agreement with findings Mulika *et al.* (2019) who reported that days to emergence were dependent on the tillage technique. Similar findings have been reported by, Leon and Owen

(2006), who found that the emergence pattern of water hemp was influenced by the tillage systems.

It was also noted that crop emergence varied significantly with variety. Variety KS20 reached 50% flowering earlier compared to variety N26 variety. This study finding has been supported by Karimi *et al*. (2019) who found out that variety KS20 had shorter flowering and maturation period compared to other green gram varieties. Several research have shown that crop flowering process is governed by the phenology of specific cultivar and the varietal genotypic characteristics. It has been reported that variety KS20 has a short maturity period (60-65 days) which could have been the reason as to why it reached 50% flowering earlier. The availability of soil moisture content, soil nutrients and other environmental factors significantly determines the number of days a crop takes to reach 50% flowering. Crops under mulched plots took longer to reach flowering compared to those in un-mulched plots. It was noted that crops under mulched plots took more days to reach 50% flowering compared to plots without mulch applied. This could be due to the conserved moisture in the soil because of applied mulch. This finding has been supported by Igbal *et al*., (2009) who reported delayed flowering in mulched plants due to favorable crop growth and available moisture compared to un-mulched plots. Delay to reach 50% flowering could be due increased soil water content resulting from reduced evaporation (Yi *et al*., 2011). Furthermore, Tangadulratana (1985) reported that the differences in crop physiological maturity to the different tillage practices results to delay in flowering and maturity. Similar results were also obtained by Sharma *et al*. (1988) who reported that different tillage systems recorded varied dates for maturity.

3.7.2 Tillage method and mulch effects on growth parameters

Tillage and mulch had significant effects on the height of plant at different growth stages and branch numbers per green gram plant. Plant height in furrow-ridge were taller compared to those under zero tillage and lowest height was under conventional tillage. The height recorded in furrow-ridge as opposed to those under zero tillage and conventional tillage could be as a result reduced soil bulk density and roots penetration to absorb water and nutrients. This result conforms to Aikins and Afuakwa (2010) who found out that plant height in deeply ploughed soil had plant height her than those in shallow plough. Plant growth is influenced by ideal environment provided by the loosened soil and the ridges which provides aeration, proper rooting and moisture storage (Khusid *et al*., 2006). Diaz-zorita (2000) also reported high plant height in tilled land compared to those in no till. Parlawar *et al*. (2017) and Jitonde *et al*. (2017)

also reported that furrow-ridge had higher plant height compared to minimum tillage in their study. The significant difference in the number of branches of the plant reported more in furrow-ridge compared to in zero tillage and conventional tillage could be due to favorable growth factors provided by root penetration soil with available water and nutrient for the plant with addition of 3 t ha^{-1} of mulch. Applied mulch significantly influenced the number of branches in both Katumani experimental site and Mwea. Plots where 3 t ha^{-1} of mulch applied had more number of branches compared to plots without mulch applied. The difference in number of plant branches could be associated to conserved moisture by the applied mulch on the soil surface as supported by Thakur *et al*. (2019) findings.

Roots biomass was significantly impacted by tillage method and applied mulch at both flowering stage and maturity. More root biomass was achieved under furrow-ridge compared to zero tillage and conventional tillage. The difference in biomass between furrow-ridge and the other two tillage method could be as a result of favorable soil conditions which creates easy root penetration and growth due to sufficient moisture and access to nutrient through absorption. This finding contradicts the findings of Sidiras *et al*. (1999) whose results had shown that high root biomass was observed under root biomass in zero-tillage compared to minimum and conventional tillage though furrow-ridge was not part of the treatment.

3.7.3 Effect of tillage methods and mulch on nodulation

Tillage and mulch significantly affected number of nodules and nodule dry weight. Number of nodules and nodule dry weight are easily affected by the amount of soil moisture and soil nutrient status. Several studies have indicated that sufficient amounts of water in the soil enhance nodulation process hence increasing the number of nodules and nodules dry weight. Sangakkara (2004) reported reduced number of nodules due to soil moisture stress. The applied mulch played an important role in increasing nodule numbers and nodule dry weight. The high number of nodules and nodules dry weight recorded in plots with mulch applied could be due soil conserved moisture and favorable temperatures for microbial activities. These findings conformed to Dukare *et al*. (2017) who reported high number of nodules in organic mulched plots compared to plots without mulch. Furthermore, increased nodulation is dependent on the soil penetrability, aeration and soil moisture content. Under this study the number of nodules was high in furrow-ridge compared to conventional and zero-tillage. This could be due to increased root establishment in furrow-ridge due to reduced compaction, aeration and increased water retention. This finding agrees with Ayanaba and Nangju (1993) findings of low nodules count in compacted soils. Furthermore, Kombiok and Buah (2013) reported higher number of nodules in deep tillage system compared to minimum and zero-tillage.

It was also noted that the number of nodules and nodules dry weight varied significantly with variety, variety KS20 recorded more nodules and nodule dry weight compared to variety N26. These variations could be attributed to the varietal differences. This finding is in agreement with Mulika *et al*. (2019) who found out variety KS20 being superior compared to KAT00308 and KAT0039 green gram varieties.

3.7.4 Influence of tillage method and mulch on yield and yield components

Pods number per plant, seeds count per pod and thousand seed weight were significantly impacted with tillage method and mulch applied. The recorded high number pods, seeds number in a pod and weight of one thousand seed in furrow-ridge than in zero tillage and conventional tillage. Applied 3 t ha-1 of plant residue mulch had a significant impact on pods number per plant, seeds count per pod and weight of a thousand seeds. The difference in pods and seeds numbers as well as the weight could be due to moisture conserved under mulched plots treatment. Variety N26 recorded a greater number of pods which could be as a result of genetic difference between the two varieties which has more branches compared to variety KS2. Furthermore, the difference could as well be attributed by Khaemba *et al*. (2016) who alluded that seeds number per pod, seeds per pod is solely dependent on genotype of the crop. Mulika *et al*. (2019) found similar results of green gram. The increased weight reported under furrow-ridge could as a result of softness, soil penetration ability and access conserved soil moisture at varied depth compared to zero tillage conventional. Khurshid *et al*. (2006) in their study found out that tillage and mulch significantly impacted maize seed weight. In addition, Khan *et al*. (2011) reported that there was significant difference in a thousand seed weight with tillage method. In their study, Teame *et al*. (2017) found out that thousand seed weight varied significantly with application of mulch. The difference thousand seed weight from variety KS20 and variety N26 could be as a result of genotypic composition. The bigger grain sizes of variety KS20 compared to variety N26 small sizes created the difference in weight. This finding is in line with Mulika *et al*. (2019) seed grain weight difference from three varieties of green gram.

Green gram grain yield and biomass was significantly impacted by tillage type and mulch applied. High grain yield and green gram biomass were recorded under furrow-ridge than in zero tillage and conventional tillage method. The difference in yields recorded in furrow-ridge could be as a result of conserved water in the furrows which provided available water for plant Applied 3 t ha^{-1} of mulch had significant effect on green gram grain yield and biomass. uptake. These findings of grain yield and biomass under contrasting tillage method and mulch is in agreement with Huang *et al*. (2012) findings of varied yield due to different tillage method and mulch application. The plots mulched recorded high green gram grain yield than those in plots without mulch. High grain yield was recorded in furrow- ridge plots with 3 t ha^{-1} mulch of plant residue and least grain yield was in conventional tillage without mulch applied. Green gram yield increased in mulched plots could be as a result of conserved soil moisture and increased soil water infiltration due to mulch. The finding conformed to those of Chakraborty *et al*. (2008) and Ogban *et al*. (2008) who found more yield of wheat and cowpea with applied mulch. Ndiso *et a*l. (2018) found out that that application of organic mulch improves moisture content of soil, growth and grain yield of corn. Kinama, 1997 and Kinama *et al*., 2007 found out that mulch increases soil moisture conservation and reduces temperature in the soil which contributes to high grain yield. Variety N26 had more grain yield than variety KS20 due to genetic variation as a result variety N26 had a greater number of branches which might have contributed to more pods and eventually seeds per pod. This finding is in agreement with Khaemba *et al*. (2016) findings on green gram grain yield of different varieties. The high plant biomass under furrow-ridge compared to other tillage practices could be due to available moisture which made easy water and nutrient uptake which prompted dry matter accumulation. This agrees with Khaemba *et al*. (2016) findings on effect of tillage methods on total above ground biomass. Furthermore, Iqbal *et al*. (2008) and Parlawar *et al*. (2017) reported high biomass with varying tillage types. Variety influenced biomass accumulation. Green gram variety N26 had more biomass than KS20. The difference could be due to genetic capability of variety N26 having more branches compared to variety KS20. Varieties that mature early tend to have less dry matter yielded compared to varieties that takes longer to mature. This finding conforms to Kitonyo *et al*. (2013) findings on early maturing varieties accumulating less biomass than those that takes longer to mature. In their study, Mulika et al. 2019 found out that growth parameters vary with the type and variety of the crop. Furthermore, Karimi *et al*. (2019) found that varied biomass accumulation is due difference in varieties. Chandra *et al*. (1998) found that pigeon peas that matures early had high harvest index compared to the varieties that mature late.

CHAPTER FOUR: DETERMINATION OF THE EFFECT OF TILLAGE METHOD AND MULCH APPLICATION ON SOIL MOISTURE CONTENT AND WATER USE EFFICIENCY OF TWO GREEN GRAM VARIETIES

4.1 Abstract

Low crop yields in ASALs of Kenya results from insufficient and inadequate soil moisture content,among other constraints. Field studies were conducted during the 2018-2019 short rain to evaluate the effect method tillage and mulch on soil moisture retention and water use efficiency of green gram in rain-fed conditions under in two experimental sits. The experiment comprises of six (6) treatments; furrow-ridge, zero tillage and conventional tillage mulched with 3 t ha^{-1} of plant residue and same tillage without mulch applied. Variety N26 and KS20 of green gram were used to conduct the experiment in each of the treatment. A randomized complete block design (RCBD) with a split-split plot layout was used for the treatment. Tillage method as the main plot, plant residue applied as mulch to cover the sub plot and finally the two green gram varieties N26 and KS20 covering the sub-sub plot with three replicates for each treatment. Soil samples were taken at 0-30 cm depth at each of the respective growth stage (vegetative, flowering and maturity) and taken to laboratory for soil moisture content determination. Analysis of data was done using GenStat statistical software and separation of mean was done by least significant differenceLSD at $P \leq 0.05$. Results indicated that soil moisture was significantly impacted by tillage methods and mulch at each growth stage of the two green gram varieties. Furrow-ridge recorded high soil moisture content than zero tillage and the lowest was under conventional tillage practices. Application of mulch significantly increased the soil moisture content with furrow-ridge and zero tillage and mulch recording the highest soil moisture content in the two sites. Combination of furrow and mulch have shown to be the effective techniques for soil moisture conservation in the two experimental sites. Therefore, it can be recommended to produce crops in areas with deficient rainfall throughout the year.

Key words: water use efficiency, zero tillage, furrow-ridge

4.2 Introduction

Water deficiency and shortages has become a global problem causing losses and limitations to agricultural production (Wang *et al.,* 2016). This challenge has been aggravated by climate changeand variability. Despite the climatic limitations, there is hope in conservation agriculture which will ensure efficient soil moisture conservation through minimal soil disturbance (Zarea, 2011). Intensive tillage methods and bare soil surface exposes the soil to agents of erosion and moisture depletion (Choudhury *et al*., 2016). The use of excessive tillage operations is harmful to soil and increase the costs of production. Conventional tillage is known to degrade soil structure (Seibutis*et al.*, 2009). Low crop production due to moisture stress aggravates food and nutritional insecurityin Sub-Saharan Africa (Das *et al*., 2015).

Managing water loss includes crop management practices and breeding aspect to enable efficient use of the limited water in the ASALs. This practice is being adopted in many semi-aridenvironments with little and unreliable rainfall like in Eastern Kenya (Johnson *et al*., 2018). Thereis need to shift from conventional tillage to zero tillage, furrow-ridge and use of mulch for the purpose of protecting soil from degradation, reducing the cost of production and increasing the water use efficiency for crops. Furthermore, the use of appropriate conservation tillage methods could provide solution to minimize climate change effects on production.
Conservation tillage such as zero tillage and furrow-ridge have been reported to improve soil physio-chemical properties and soil water use efficiency (WUE) (Bottinelli *et al.,* 2017). Improvedtillage methods also affect soil water holding capacity, soil temperature, infiltration, and evapotranspiration process (Busari *et al.,* 2015).

Zero tillage and furrow-ridge increase crop yield as a result of nutrient and moisture availability Micheni *et al.* (2014). Water productivity is a key challenge that needs to be improved by an on- farm water balance (Rockstrom *et al*., 2003). Mulch application in addition to the use of conservation tillage method provides effective measures to reduce soil water evaporation, improving the soil moisture retention capacity, making water available for uptake and increasing water use efficiency (Li *et al*., 2016).

4.3 Materials and Methods

4.3.1 Experimental site description

This section has been described in chapter 3 of this thesis. The experiment was carried in Machakos county KALRO based in Katumani and KALRO of Mwea under Kirinyaga County during the short rains of year 2018/2019 as described in chapter 3, section 3.1 of this thesis.

4.3.2 Experimental layout, design and treatments

The experiment was laid out in a randomized complete block designed in a split-split plot arrangement with tillage; conventional, furrow-ridge and zai pits in the main plot. Mulch was applied at the rate of (0 and 30 t ha^{-1}) in the sub-plot, while varieties (KS20 and N26) were planted in the sub-sub plot, replicated three times.

4.3.3 Experiment management

Crop husbandry practices were applied from land preparation, planting, weeding, pest and disease control as described in chapter 3, section 3.3.3 of this thesis.

4.4 Data collection

Data on soil moisture was determined at three different growth stages (vegetative, flowering and maturity). Soil samples were collected randomly at a depth of 0-15 and 15-30 cm from each plot using a soil auger. The soil samples were composited and a representative soil sample was put in airtight moisture cans and covered with lid for determination of fresh weight. The samples were then taken to the laboratory and oven-dried for 24 hours under 105 ^{0}C and then measured for dry weight. Soil moisture was then determined gravimetrically using (Eqn 2)

$$\text{Soil moisture content (\%)} = \frac{\text{Fresh weight} - \text{dry weight}}{\text{dry weight}} \; x \; 100 \ldots\ldots (2)$$

The gravimetric water content was converted into volumetric water content by multiplying with the bulk density as in Equ 3.

$$\theta = \acute{\omega}\rho b \div \rho w \ldots\ldots (3)$$

Where,

θ - Volumetric water content, ώ- Gravimetric water content, ρb- soil bulk density, ρw- density of water (g/cm^3)

Water use efficiency was calculated from the ratio of economic grain yield to the difference between seasonal rainfall and soil moisture at maturity (evapotranspiration) (Eqn 4). Cumulative seasonal rainfall was obtained by summation of monthly rainfall within the crop growth season from sowing to maturity.

$$\text{Water use efficiency} = \frac{\text{ecinomic yield}}{\text{seasonal rainfall} - \text{soil moisture at maturity}} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (4)$$

4.4.1 Soil moisture retention curve

The soil moisture retention curve (pF curve) elucidates the capacity of the soil to retain moisture. Depending on the soil textural class, the pF curve shows tremendous value as early warning tool

reminding of critical point in moisture levels during plant phenological stages under rain fed conditions. This curve helps field managers take preventive measures to avoid crop failure during production. Higher moisture retention curve in water during crop production not only increases crop water use efficiency, but also facilitates the structural adjustment needed by agronomists (Deng *et al*., 2006). Research by Cakir (2004) has shown that not all plants have the same wilting point because of the difference in the root distribution and moisture absorption capacity from the soil by plant roots. Soils of the study area showed that field capacity is reached at pF 2 to 2.5 and relative available water (RAW) at pF 3.7 or 5.0 bars and wilting point at 4.2 or 15.0 bars (Figures 4.1 and 4.2) in Katumani and Mwea. Due to high evapotranspiration rates in arid and semi-arid lands (ASALs) and high stress factors on crops, pF 2.3 to 3.7 can be suspected to give more accurate value of the actual available soil moisture in theexperimental sites.

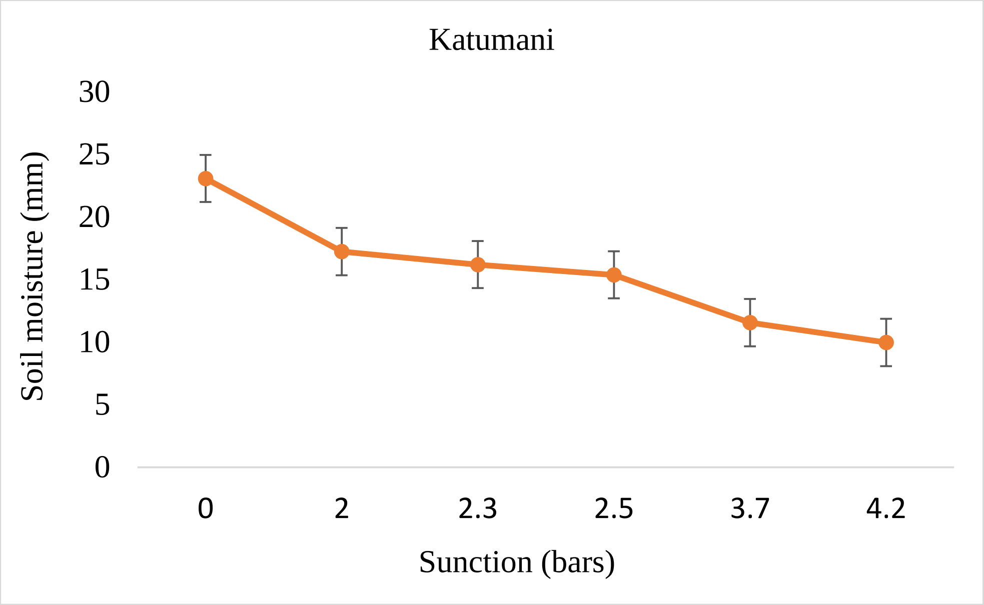

Figure 4. 1: Graph of soil moisture retention at Katumani experimental site, error bars show the standard error of mean.

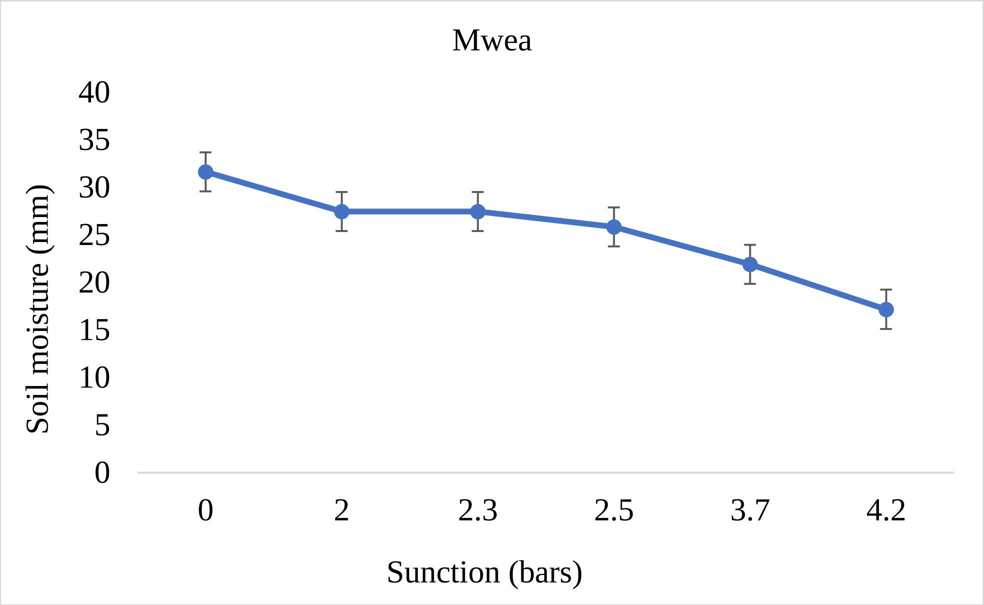

Figure 4. 2: Graph of soil moisture retention at Mwea experimental site, error bars show the standard error of mean.

4.5 Data analysis

Data on soil moisture content and water use efficiency were analyzed using GenStat 15th edition statistical package for analysis of variance (ANOVA). Mean separation was calculated using least significant difference LSD at 5% probability.

4.6 Results

4.6.1 Effect of tillage and mulch on soil moisture at different physiological stages

Soil moisture recorded at 30 days after planting (vegetative) varied significantly ($P \leq 0.05$) with tillage methods in both sites (Table 4.1). In Katumani, high soil moisture (21.71 cm^3) was recorded under furrow-ridge and in no till than in conventional tillage. Similar trend observed in Mwea where furrow-ridge and zero tillage recorded the highest (11.37 cm^3) soil moisture than conventional tillage.

Significant ($P \leq 0.05$) effect of mulch was noticed on soil moisture retention. Plots mulched with 3t ha^{-1} plant residues conserved more moisture than plots without mulch. Mulch plots had an increase of 21.24 cm^3 in Katumani and 9.06 cm^3 in Mwea compared to un-mulched plots. Variety significantly ($P \leq 0.05$) affected soil moisture at vegetative stage. Plots with variety N26 recordedhigh soil moisture content of about (73.1 cm^3) compared to those with KS20 (69.7 cm^3) in Katumani and (55.3 cm^3) and 52.8 cm^3) in Mwea respectively.

Interaction between tillage and mulch had significantly ($P \leq 0.05$) impacted soil moisture retention30 DAP (Appendix 6). Zero tillage mulched with applied 3 t ha^{-1} of plant residues had high moisture content (91.94 cm^3) in Katumani and (65.38 cm^3) in Mwea and the lowest (48.36 cm^3) and (44.00 cm^3) inconventional tillage in Katumani and Mwea respectively. There was no significant ($P > 0.05$) difference reported on interactions between tillage × variety as well as tillage × mulch × variety.

There was significant ($P \leq 0.05$) effect of tillage on soil moisture retention at the flowering stage inboth Katumani and Mwea (Table 1.0). Both furrow-ridge and zero tillage conserved more water by (13.73 cm^3) and (10.10 cm^3) than conventional tillage in the two study sites. Soil moisture at flowering stage varied significantly ($P < 0.001$) with mulch application in both Katumani and Mwea. Mulched plots recorded 21.7 cm^3 Katumani and 8mm in Mwea more than in plots without mulch.

Variety significantly ($P \leq 0.05$) affected the retention of moisture in the soil at flowering stage (40 DAP) in Katumani experimental site and in Mwea. Plots with N26 green gram variety stored high moisture than in plots with KS20 green gram variety in Mwea and Katumani. Interaction between tillage and mulch significantly ($P \leq 0.05$) affected soil moisture at flowering in both sites while the rest of the interactions were not significant. Zero tillage mulched with 3 t ha^{-1} of plant residue stored high soil moisture (77.6 cm^3) in Katumani and (49.9 cm^3) in Mwea

At maturity, soil moisture retention varied significantly ($P \leq 0.05$) with tillage in Katumani and Mwea. Zero tillage recorded high soil moisture (16.78 cm^3) and low moisture retention was observed in conventional tillage with (11.65 cm^3) in Katumani and 14.17 $cm^3$and 9.11 cm^3 in Mwea respectively.

It was also noted that mulching significantly ($P <0.001$) affected moisture at maturity in the two sites. Application of 3 t ha^{-1} mulch of plant remains increased the amount of water recorded at maturity by 4.64 cm^3 and 4.0 cm^3 compared to those where no mulch was applied in Katumani and Mwea. Variety significantly ($P < 0.001$) affected soil moisture recorded at maturity in Mwea, but no significant effect was observed in Katumani at ($P = 0.294$). In Mwea, N26 variety recorded highersoil moisture (12.17 cm^3) compared to KS20 variety (11.33 cm^3).

The interaction of tillage × mulch × variety positively ($P \leq 0.05$) impacted the retention of moisturein the soil in Katumani and Mwea. Variety N26 under no till mulched with 3 t ha^{-1} of plant residue highest moisture content (19.75 cm^3) and (17.03 cm^3) and the lowest was observed withvariety KS20 variety with (8.88 cm^3) and (5.88 cm^3) in conventional tillage plots without mulch applied.

Table 4. 1: Soil moisture content (cm^3/cm^3) at different phenological stages in Katumani and Mwea

Treatment + interaction	Katumani			Mwea		
	Vegetative	Flowering	Maturity	Vegetative	Flowering	Maturity
Conventional	56.95b	47.69b	11.65b	48.76c	30.21b	9.13c
Furrow-ridge	81.44a	62.54a	13.78b	53.22b	38.45a	11.95b
Zero	75.87a	60.29a	16.78a	60.13a	42.06a	14.17a
LSD	18	5.55	2.84	3.42	7.05	1.59
P-Value	0.041	0.003	0.018	0.002	0.022	0.002
Mulch						
0 t/ha	60.78b	46.0b	16.39a	49.5b	32.9b	9.73b
3 t/ha	82.06a	67.7a	11.75b	58.6a	40.9a	13.77a
LSD	5.2	5.32	2.88	3.01	3.25	0.77
P-Value	<.001	<.001	<.001	<.001	<.001	<.001
Variety						
KS20	69.7b	55.1b	13.9a	52.8b	35.8b	11.3b
N26	73.1a	58.6a	14.3a	55.3a	38.0a	12.2a
LSD	3.25	2.89	0.89	1.3	0.93	0.41
P-Value	0.04	0.02	0.294	0.001	<.001	<.001
P values for interactions						
Tillage × Mulch	0.03	0.69	0.04	0.05	0.1	0.05
Tillage × Variety	0.72	0.24	0.51	0.45	1	0.06
Mulch × Variety	0.8	0.27	0.48	0.83	0.5	0.83
Tillage x Mulch × Variety	0.36	0.05	0.59	0.12	0.03	0.03

LSD: Least Significant Difference; Means followed by the same letter are not significantly different at $P \leq 0.05$

4.6.2 Effects of tillage methods and mulch application on water use efficiency (WUE)

Figure 4.3 and 4.4 below presents the effects of contrasting tillage methods and mulch applicationon water use efficiency of two green gram varieties.

Water use efficiency of green gram was significantly ($P < 0.001$) affected by tillage methods in Katumani, but no significant difference was recorded in Mwea. It was noted that crops under furrow-ridge recorded higher water use efficiency compared to those grown under conventional and zero-tillage (Figure 4.3 and 4.4).

Mulching significantly ($P \leq 0.05$) impacted water use efficiency of green grams in both Katumani and Mwea. Crops in 3 t ha^{-1} of mulch utilized water efficiently compared to those in plots without applied mulch.

Variety significantly (P < 0.001) influenced water use efficiency in Katumani and Mwea. Variety N26 significantly recorded higher water use efficiency than variety KS20 in Katumani and Mwea.

Interaction of tillage and mulch had no significant (P ≥ 0.05) effect on water use efficiency. However, tillage × variety, much × variety and tillage × mulch × variety significantly (P ≤ 0.05) affected water use efficiency in Katumani, but no similar trends were observed in Mwea.

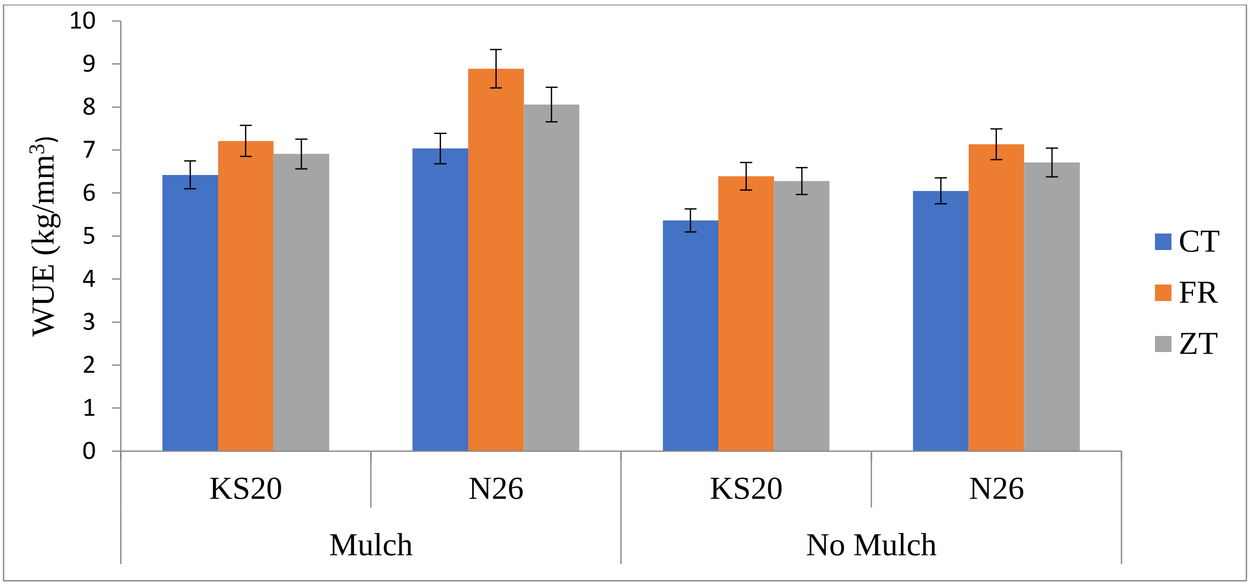

Figure 4. 3: Water use efficiency of green grams under different tillage methods and mulch inKatumani. Error bars shows standard error mean.

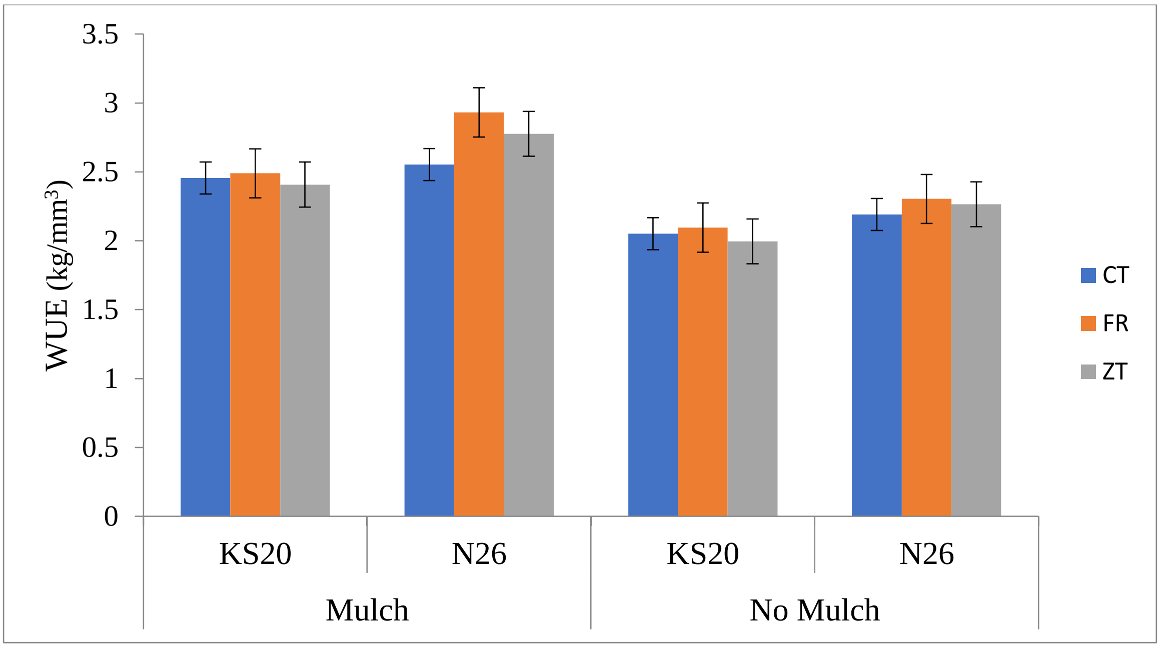

Figure 4. 4: Water use efficiency of green grams under different tillage types and mulching in KARLO Mwea. Error bars shows standard error of mean

4.6.3 Relationship between soil moisture content, yield and yield components

In Katumani, biomass and yield were positively correlated with soil moisture. A positive relationship between biomass at (flowering and maturity) and yield varied with moisture on the two green gram varieties N26 (R^2= 0.6639 and R^2= 0.0884) and R^2 = 0.2356 and KS20 (R^2= 0.1762 and R^2= 0.0444) and R^2= 0. 0486, respectively.

In Mwea, biomass (flowering and maturity) and yield were positively correlated with soil moisture.A positive relationship between biomass at (flowering and maturity) and yield varied with moistureon two green gram varieties N26 (R^2= 0.4937 and R^2 = 0.4061) and R^2 =0.4689 and KS20 (R^2 = 0.3289 and R^2 = 0.1621) and R^2 = 0.4319, respectively. The correlation analysis has shown that variety N26 recorded a significant positive relationship (R^2 = 0.6639) between soil moisture and biomass at flowering compared to variety KS20. This reported significant correlation could be attributed to the high number of branches that variety N26 had compared to KS20, that acts a soil cover, reducing the rate of evapotranspiration from direct sunlight.

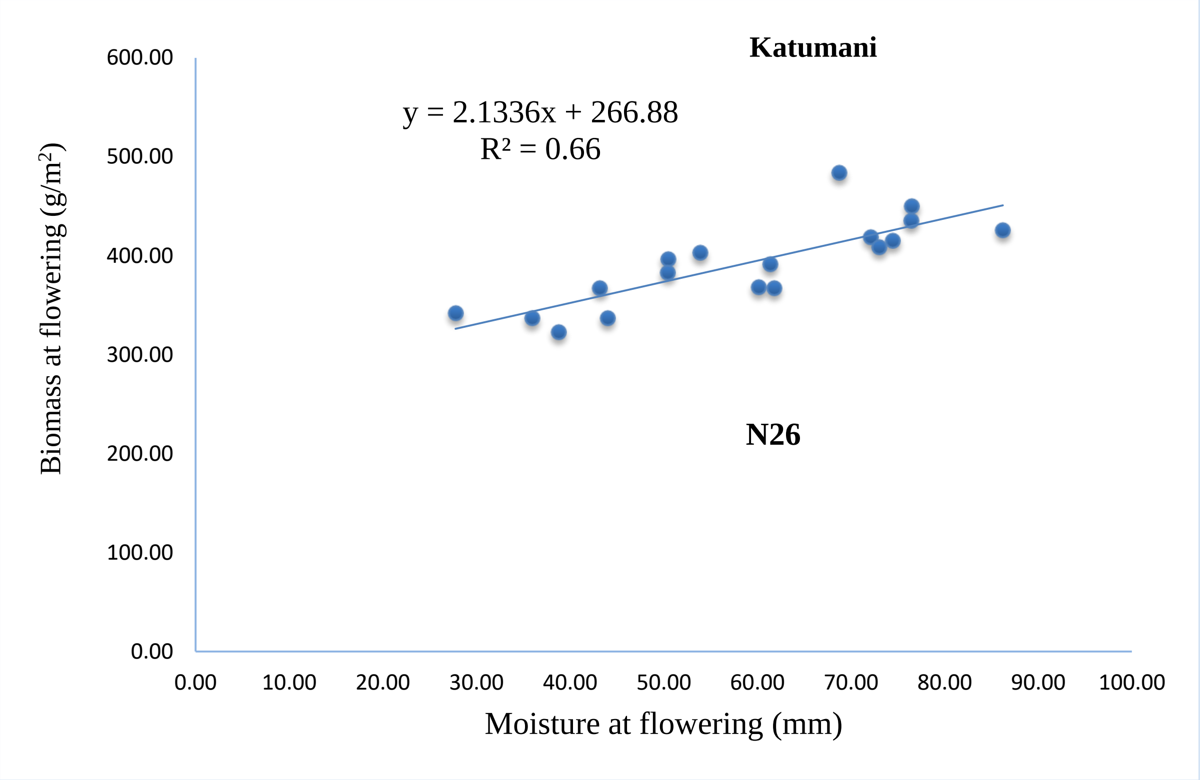

Figure 4. 5: Relationship between moisture at flowering and biomass at flowering for N26

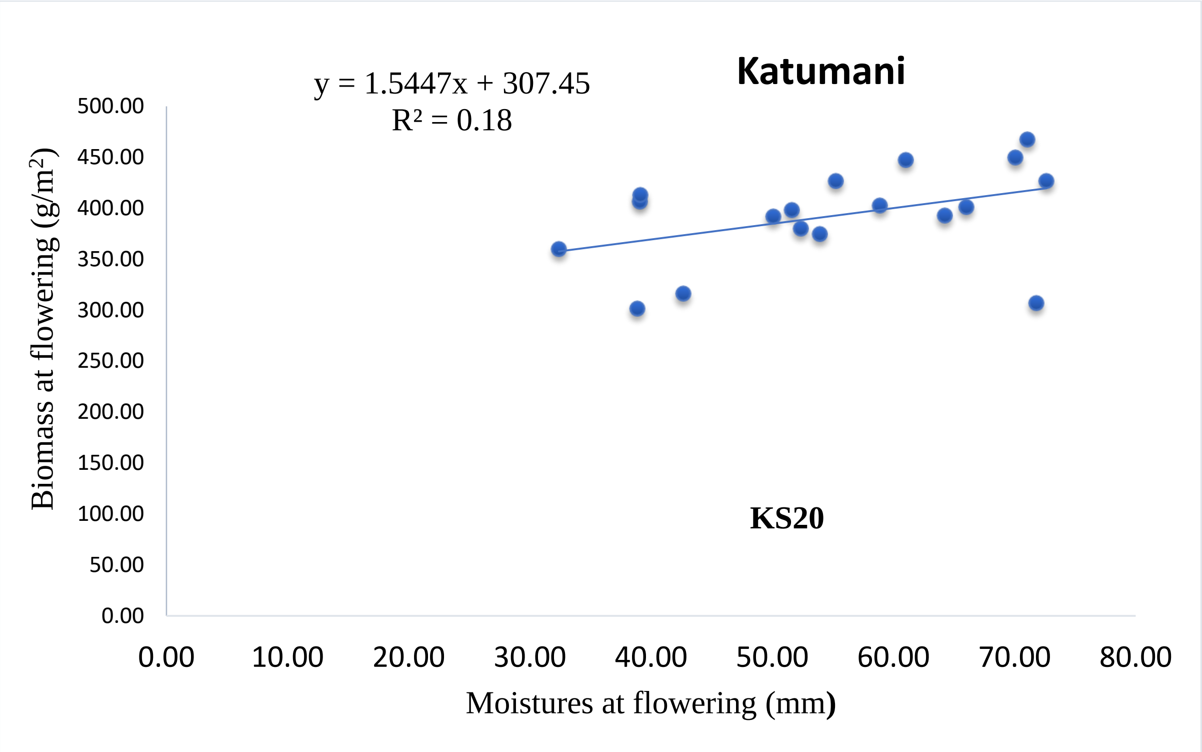

Figure 4. 6 : Relationship between moisture at flowering and biomass at flowering for KS20

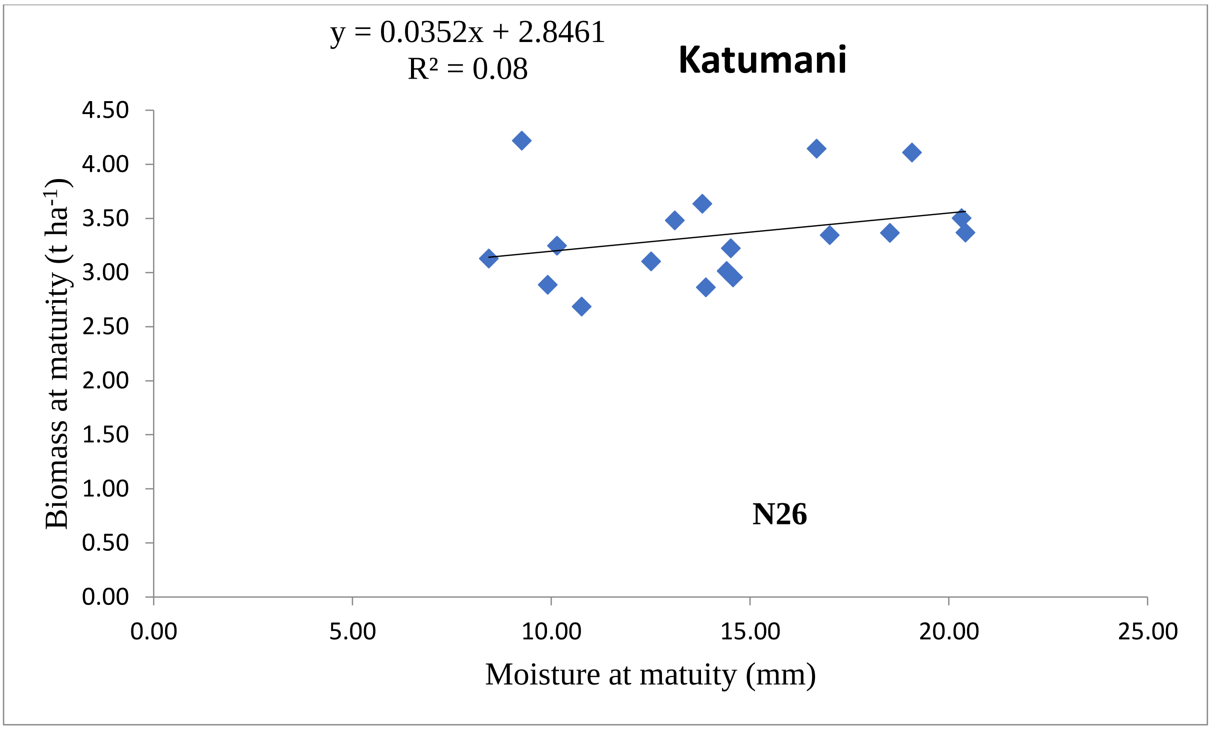

Figure 4. 7 : Relationship between moisture at maturity and biomass at maturity for N26

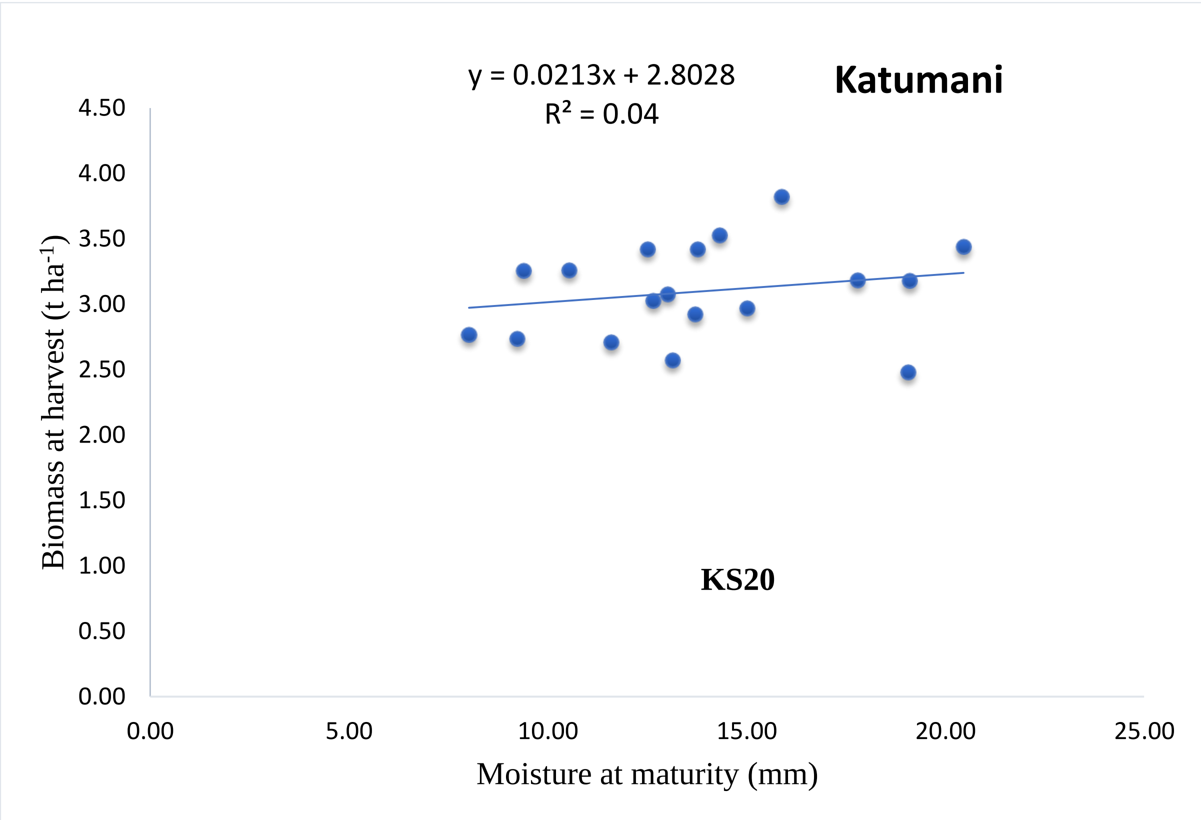

Figure 4. 8 : Relationship between moisture at maturity and biomass at maturity for KS20

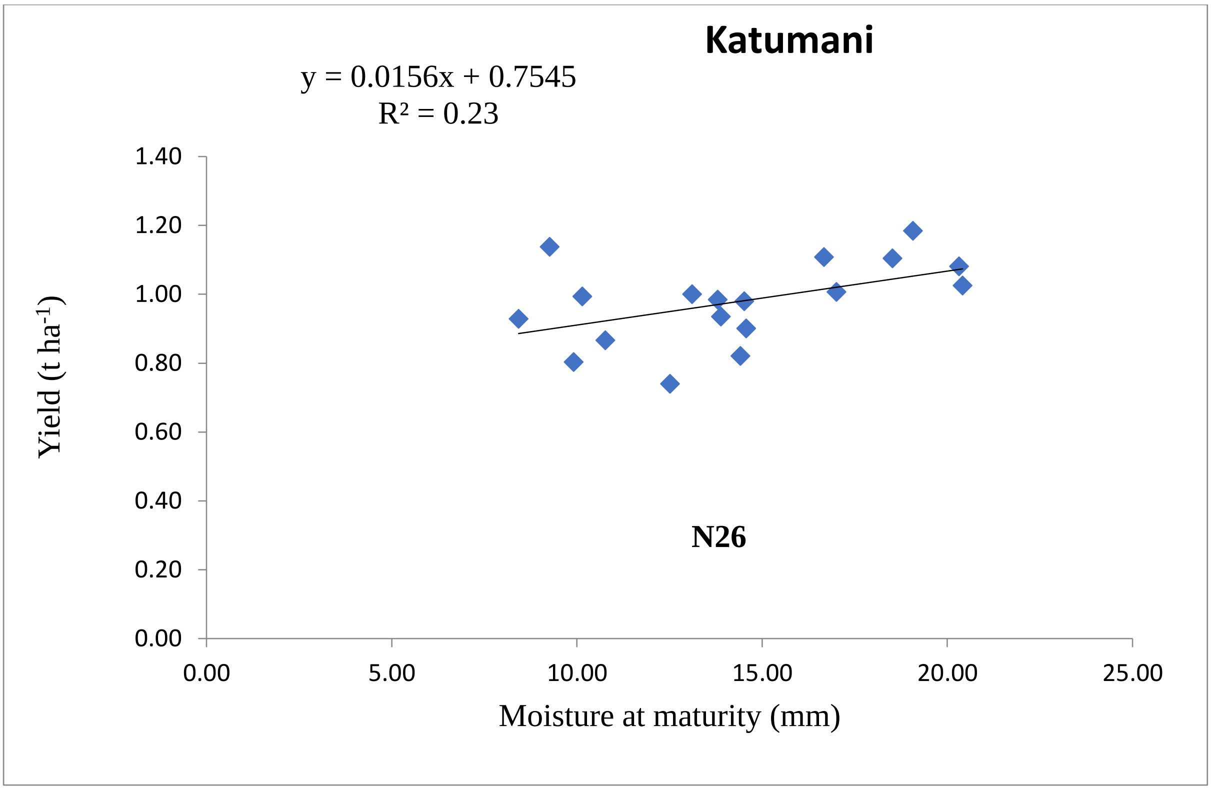

Figure 4. 9: Relationship between moisture at maturity and grain yield for N26

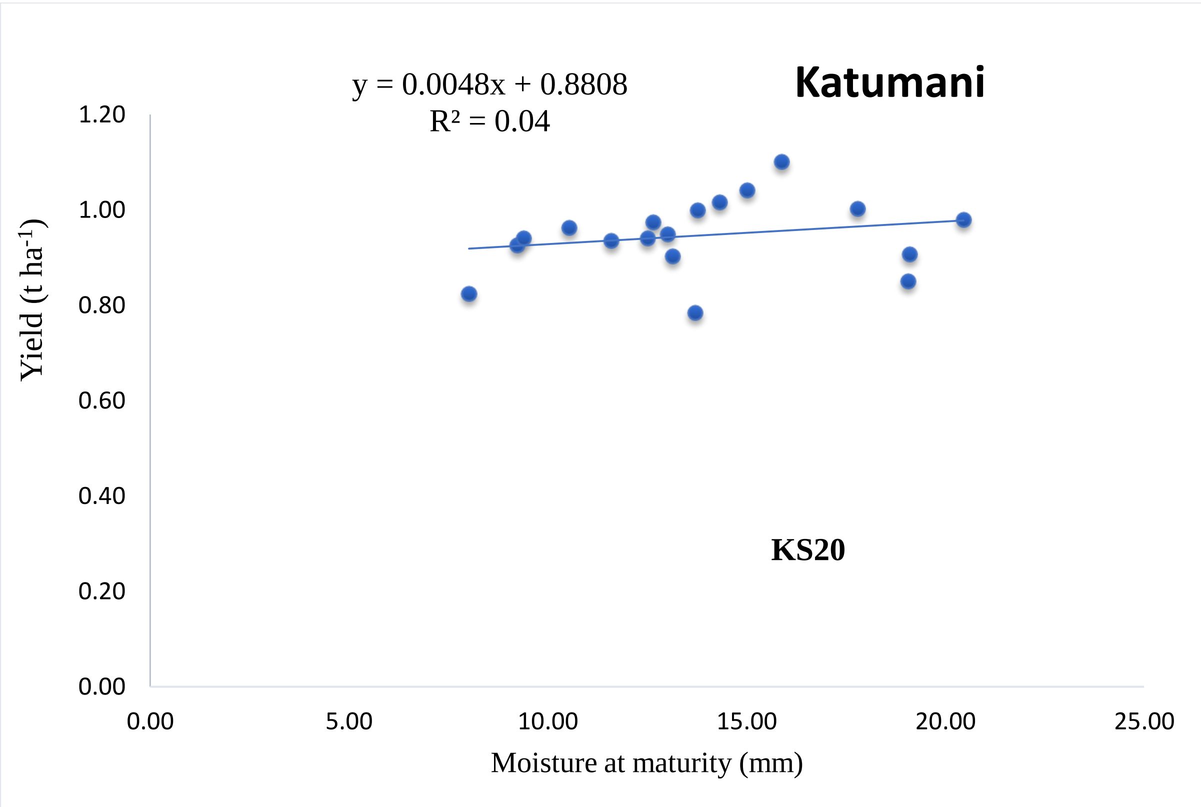

Figure 4. 10: Relationship between moisture at maturity and grain yield for KS20

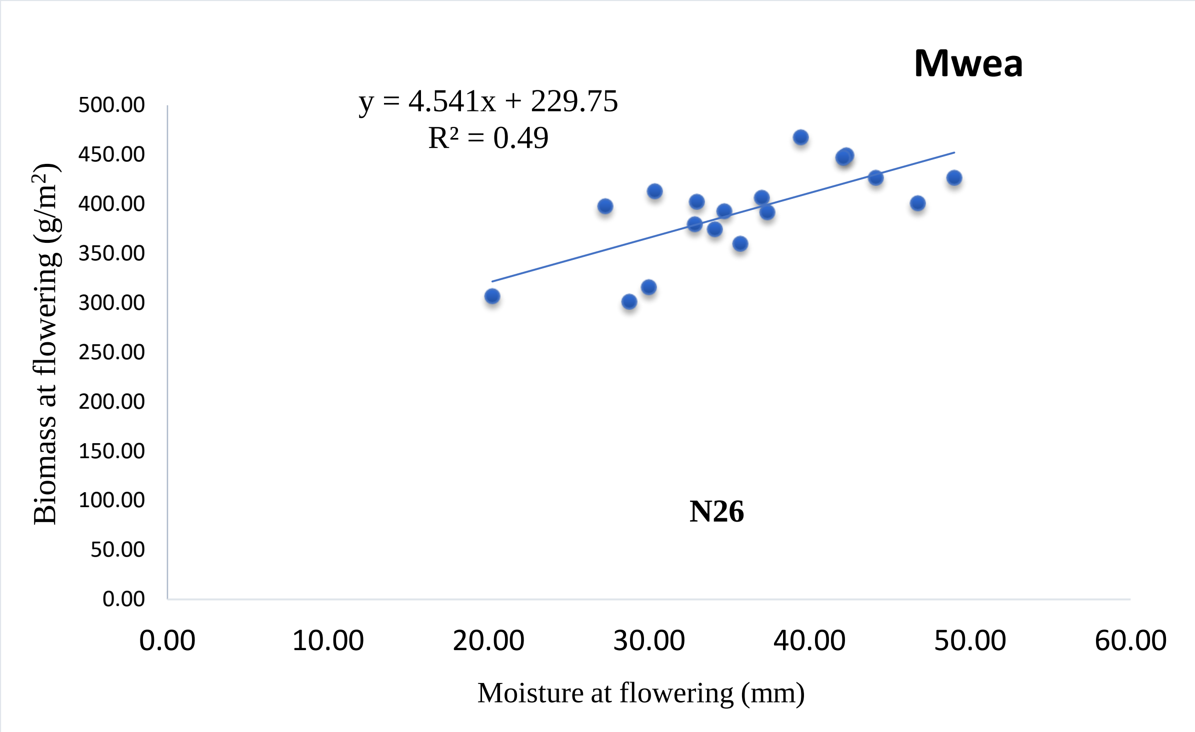

Figure 4. 11: Relationship between moisture at flowering and biomass at flowering for N26 in Mwea

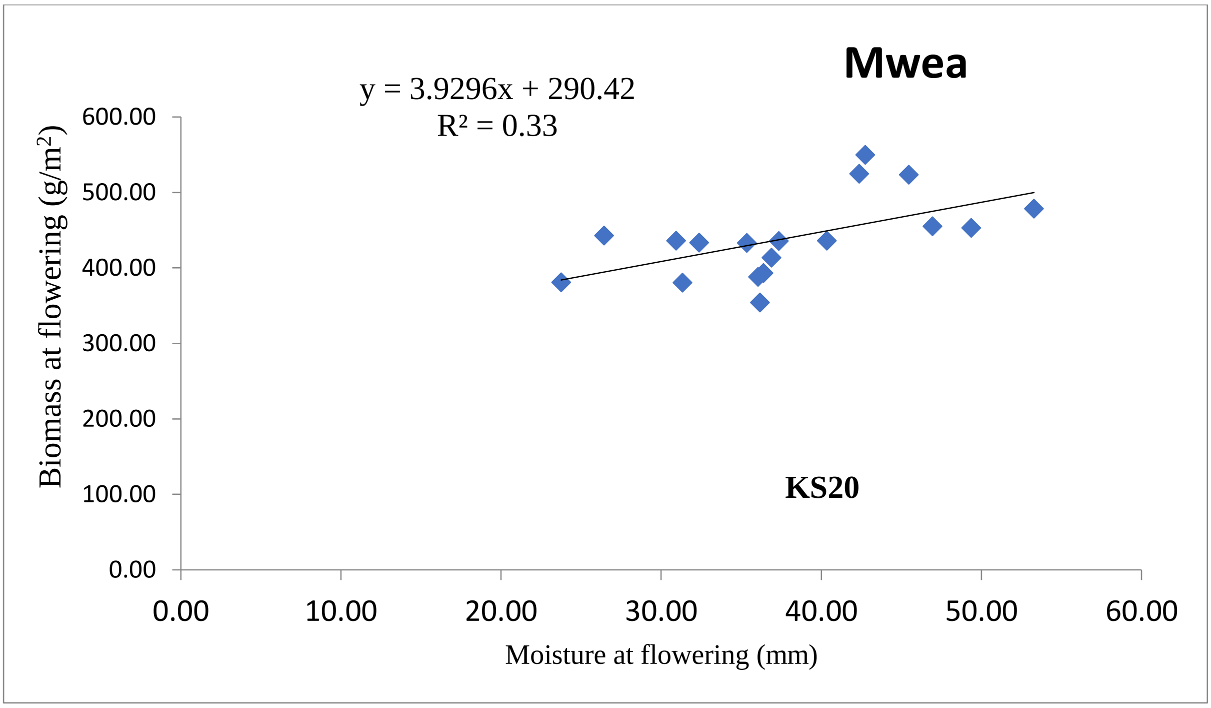

Figure 4. 12: Relationship between moisture at flowering and biomass at flowering for KS20 in Mwea

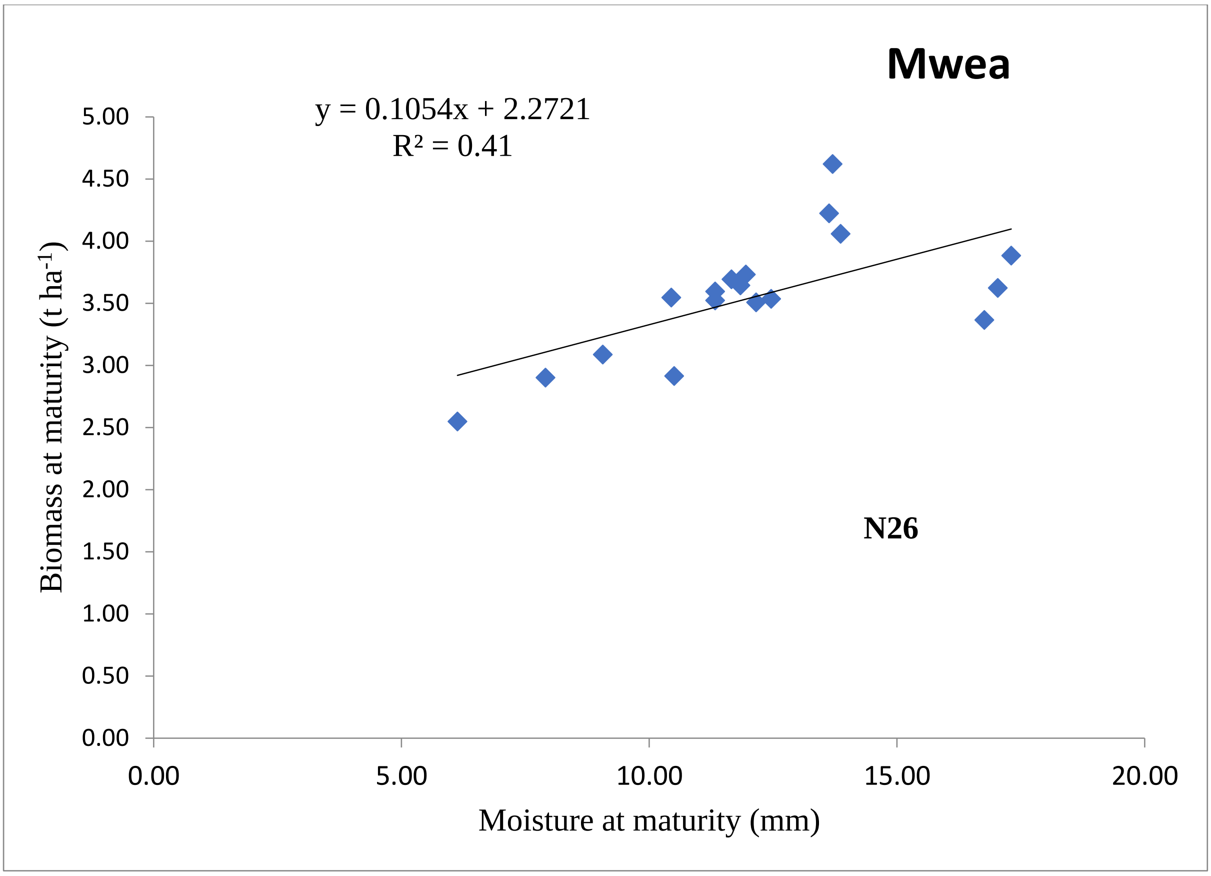

Figure 4. 13: Relationship between moisture at maturity and biomass at maturity for N26 in Mwea

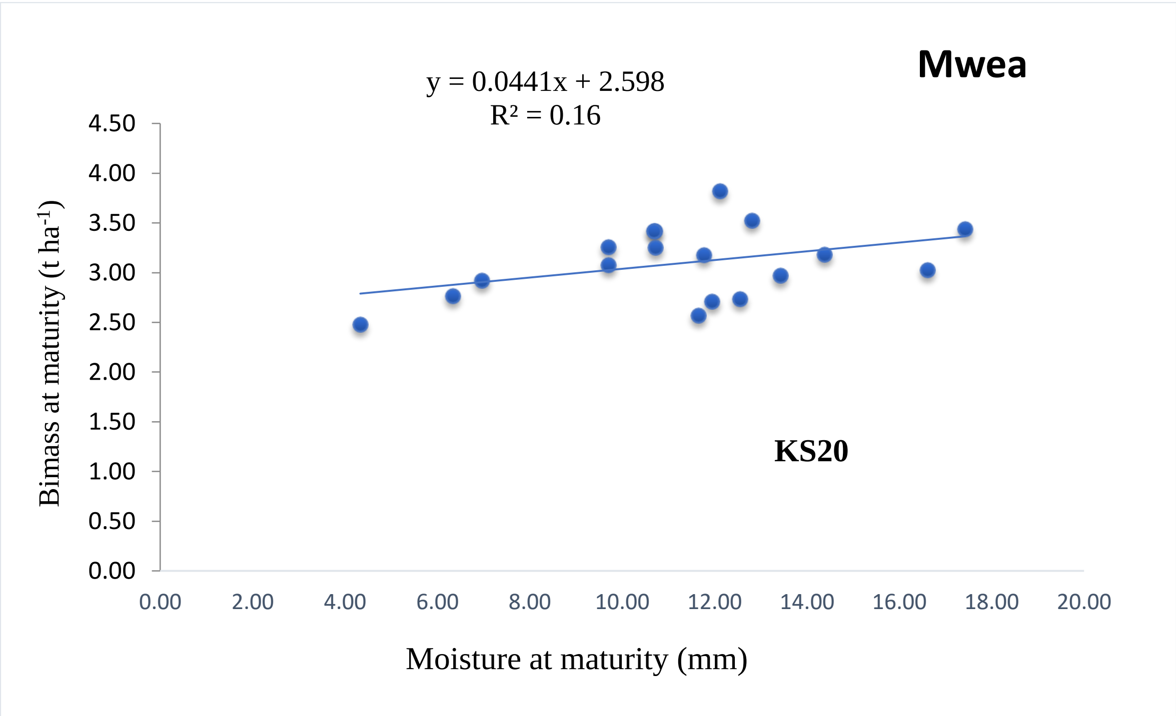

Figure 4. 14: Relationship between moisture at maturity and biomass at maturity for KS20 in Mwea

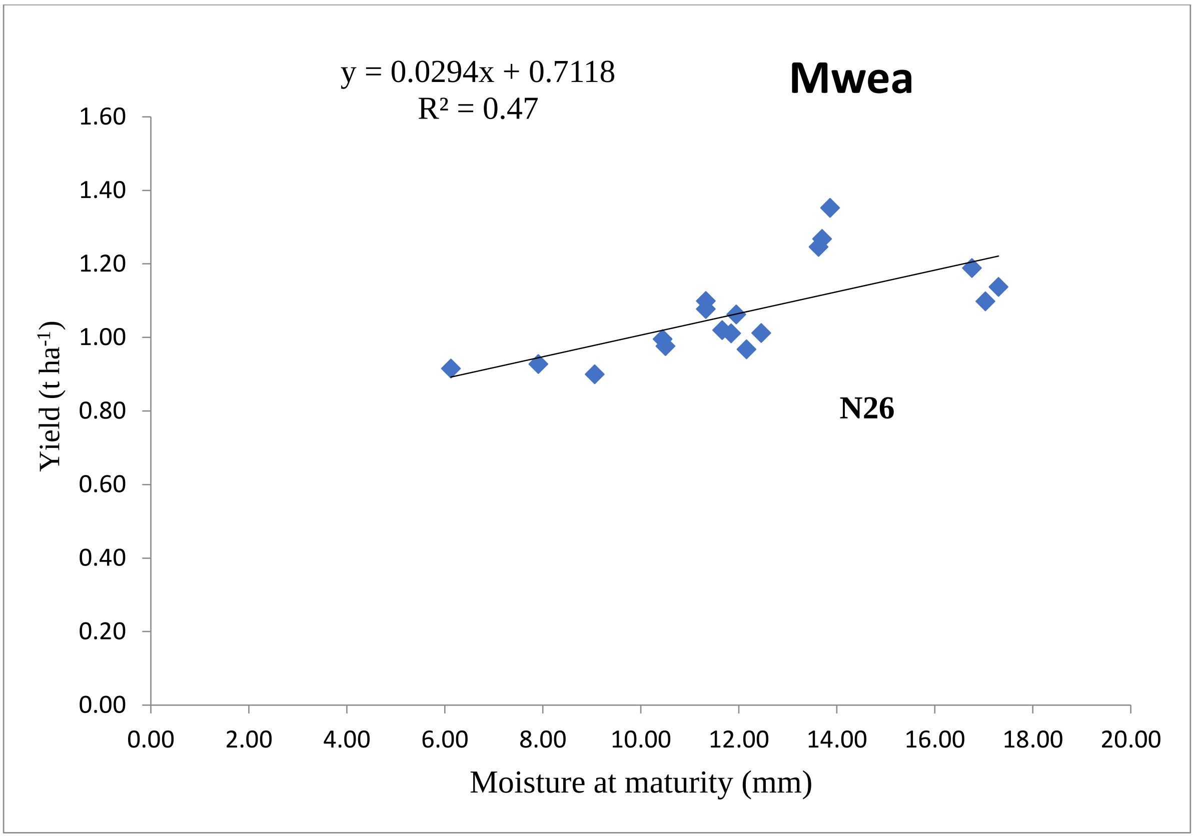

Figure 4. 15: Relationship between moisture at maturity and grain yield for N26 in Mwea

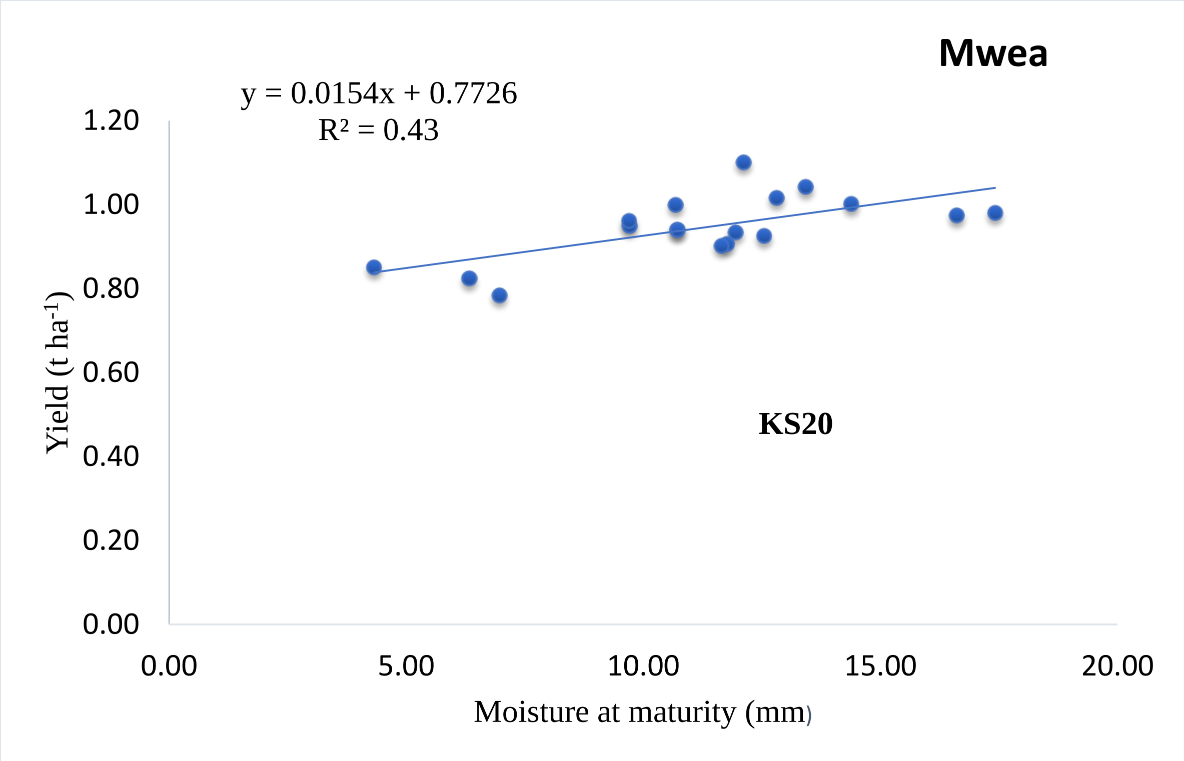

Figure 4. 16: Relationship between moisture at maturity and grain yield for KS20 in Mwea

4.7 Discussion

4.7.1 Tillage and mulch effect on soil moisture retention

Tillage and applied mulch had significant effect of tillage methods and mulch application on soil moisture retentionat vegetative, flowering and maturity. High soil moisture was stored in furrow ridge and zero tillage with applied 3 t ha^{-1} of plant residues than in conventional tillage. This result agrees with the findings of Chepkemoi *et al.* (2014) about high soil moisture content in furrow- ridge than in conventional tillage. Furrow-ridge and no till have the capacity to hold more water compared to conventional tillage. Furrows stores water temporary during rain which is used later by crops for their growth and development (Dile *et al*., 2013).

The significant effect of mulch application on soil moisture content is attributed to the shielding effect of mulch to the soil surface from direct sunlight hence reduced evapotranspiration. According to Acharya *et al.* (2005) mulching reduces evaporation from the soil surface by retarding the intensity of the radiation and wind velocity on the mulched surface. This explains thefaster soil moisture decline in no mulch treatments compared to where mulch was applied. Mulch application contributes to the maintenance of soil physical structure, and results in better soil moisture retention. The decomposition and mineralization of the mulching materials binds thesoil particles together, hence improving water holding capacity (Karuku, 2018). Surface mulchingshades the soil which prevents soil water loss by evaporation (Huang *et al*., 2005, Mulumba and Lal 2008). Similar results were reported by Temesgen (2010).

These have also been reported by Suge *et al.* (2011) and Dejene and Lemlem (2012), who found that addition of mulch improved soil water holding capacity of the soil. Mulch reduces evaporation and retains moisture to provide more water to plants (McMillen, 2013). Furthermore, the mulch, especially straw mulches, can also increase the organic matter content of the soil (Tian *et al.* 2013).
A study by Chalker-Scott (2007) documented a 35% reduction in evaporation when straw was applied in crop production. Variety N26 significantly conserved more water compared to KS20. This is because, the variety N26 grows many brunches that cover the soil from direct sunlight, hence reducing the evapotranspiration rate. Under vegetative stage, water conservation was largely due to early high leaf area index and higher leaf area coverage. This has been reported to reduce water evaporation, and improve soil moisture conservation (Ghanbari *et al*., 2010). Furthermore, distribution of root systems among different varietal

species, addition of mulching materials and tillage practices influenced soil moisture content in the soil. When crops are grown, the distribution of the roots in the soil is more intense as opposed to when grown on a bare soil.

The retention of residues on soil surface reduces water runoff, evaporation loss and more water stored in the soil profile (Busari *et al*., 2015). These findings are in accord with those of Chaudhary *et al.* (2013). In a similar study by Sharma *et al*. (2011), soil moisture recorded in no-till fields with crop residues was greater than in conventional tillage without crop residues.

4.7.2 Tillage and mulching effect on water use efficiency of green gram varieties

Crop water use efficiency depends on water availability and soil nutrient supply. The high-water use efficiency under plots with 3 t ha^{-1} of applied plant residue as mulch in furrow-ridge could be attributed to the availability of moisture that led to increased yield. Furrow-ridge acts as storage sink for water during rain making water readily available for crop uptake. In their study, Liu et al. (2014) reported an increase in crop yield and water use efficiency under tied ridges because of availability of stored water in the ridges. Greater amounts of stored soil water could support crop growth, providing ideal conditions for biomass accumulation, high water use efficiency and increased grain yield (Nielsen *et al*., 2010).

Mulching covers the soil surface and reduces the rate of evapotranspiration, making water readily available for plants uptake. The high-water use efficiency recorded by variety N26 could be due to more branches that covers the soil and reduces the amount of water loss. This means that all the water stored in the soil was utilized efficiently for grain production

CHAPTER FIVE: GENERAL DISCUSSION, CONCLUSION AND RECOMMENDATION

5.1 General discussion

This study focused on assessing the effects of tillage and mulch on soil moisture retention, crop growth, nodulation, and yield of green gram.

There were reported variations on growth, nodulation, yield and yield components of green gram in the two sites affected by tillage and mulch application. Similar findings were also recorded on soil moisture retention and water use efficiency. Furrow-ridge mulched with 3 t ha^{-1} residue of plant led to an increase in yield components of the two green gram varieties, recorded in the two study sites. These findings have been supported by Mahli *et al.* (2006). Addition of 3 t ha^{-1} mulching materials significantly improved the soil moisture content which further led to increase in crop yield. This was principally due to the increase in the organic matter content and other macro and micronutrients availability in the soil (Ndiso *et al.*, 2018). Furrow ridge system and mulchingsignificantly increased both the grain and biomass yields.

Soil moisture varied with tillage methods and mulch application. Soil moisture was measure at a depth of 0-30 cm at different crop growth stages (vegetative, flowering and maturity) in the two study sites (Katumani and Mwea). At vegetative stage, high amount of soil moisture was stored in furrow-ridge plots then zero-tillage and finally in conventional tillage. Similar findings were recorded in the subsequent growth stages i.e., flowering and maturity. Addition of 3 t ha^{-1} of mulch materials also significantly influenced the soil moisture retention. Results on water use efficiency showed that crops in mulched ridge-furrow with 3 t ha^{-1} reside of plant had efficient water use. The study showed that grain and water use efficiency of green gram under furrow-ridge with mulchwas superior compared to conventional and zero tillage. There was positive correlation between the amount of moisture retained in the soil and grain and biomass yield. This corroborates with the findings of several other studies which demonstrated positive correlation between soil moisture retention and mulch on grain and biomass yields. For instance, Chepkemoi *et al.* (2014**)** reported significant effects of soil moisture retention on crop growth and performance. Karuma *et al.* (2016) also reported increased maize grain and biomass yield because of improved soil moisture conservation. This result also supports the hypothesis which state tillage and mulch application positively influence the soil moisture retention, water usefficiency (WUE) and yield of green gram varieties.

Although the two green gram varieties are drought tolerant, it was reported that their performance in the semi-arid areas was dependent on the amount of rainfall received during the growth of the crop. Green gram N26 variety had more grains and biomass compared to KS20 variety but it took longer to mature. Significantly high grain and biomass yields recorded in varietyN26 could be attributed by its higher number of branches, more pods per plant and a greater number of seeds per pod. Variety KS20 showed consistency in early maturity in the two sites.

Variety KS20 can be adopted in the semi-arid regions if it is planted early in the season to optimizeuse of the available resources especially soil moisture. Based on duration of maturity, varietyN26 may not be recommended for the semi-arid regions due to its long maturity duration but canbe grown in areas that receive adequate amounts of rainfall.

5.2 Conclusion

The study has established that integration of tillage methods and mulch significantly increased soil moisture retention and water use efficiency of the green gram in KARLO Katumani and Mwea. Combination of furrow-ridge with mulch applicationpotentially increase green gram yields in arid and semi-arid environments where the crop is increasingly being grown. Higher nodules, nodules dry weight, yield and yield components of the two green gram varieties were recorded under ridge-furrow following application of 3 t ha^{-1} of mulch. It was worth noting that more moisture was conserved in furrow ridge and zero-tillage thanin conventional tillage. Similarly, there was a higher water use efficiency recorded under furrow-ridge system. Further, there was a positive correlation between green gram biomass yield and soil moisture content recorded at flowering.

5.3 Recommendations

- The study recommends the increase of mulching materials to a higher rate so as to monitor their effects on green gram yield and yield components.
- A similar study to be done on the effects of tillage and mulch on green gram senescence
- Another study could be done on the effects of tillage and mulch on nutrient uptake and nutrient use efficiency
- This study did not consider the cost of making the furrow-ridges, maintaining zero-tillage which may be expensive to the smallholder farmers, especially if they have to construct new ridges at start of every season and therefore invites further studies.

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APPENDICES

Appendix 1: Interaction between tillage and mulch on days to 75% maturity of two green gram varieties

Tillage	Katumani			Mwea		
	(3 t/ha)	(0 t/ha)	Mean	(3 t/ha)	(0 t/ha)	Mean
Conventional tillage	75a	70b	72	73b	71b	72
Furrow-ridge	77a	75a	76	76a	74a	75
Zero tillage	76a	73a	74	75a	73a	74
Mean	76	73		74.94	73	
LSD	3			1.65		
P Value	0.01			0.03		

Appendix 2: Effect of interaction between tillage and mulch on plant height at vegetative stage

Tillage	Katumani			Mwea		
	(3 t/ha)	(0 t/ha)	Mean	(3 t/ha)	(0 t/ha)	Mean
Conventional tillage	40.42b	35.20b	37.81	32.42b	29.48b	30.95
Furrow-ridge	47.52a	40.57a	44.04	39.63a	33.88a	36.76
Zero tillage	41.23b	37.18b	39.21	35.18b	30.40b	32.79
Mean	43.06	37.65		35.74	33.15	
LSD	3.3			2.82		
P Value	0.014			0.032		

LSD is least significant difference; means followed by same letter are not significantly different at $P \leq 0.05$

Appendix 3: Effect of interaction between tillage and mulch on plant height at flowering stage

Tillage	Katumani			Mwea		
	(3 t/ha)	(0/ha)	Mean	(3 t/ha)	(0 t/ha)	Mean
Conventional tillage	52.72b	47.28b	49.92	51.90b	42.77b	47.33
Furrow-ridge	64.19a	56.52a	60.77	58.07a	52.30a	55.18
Zero tillage	52.56b	42.27c	47.50	42.42c	36.98c	39.7
Mean	66.77	58.69		50.7	44.02	
LSD	2.23			4.812		
P Value	0.003			0.054		

LSD is least significant difference; means followed by same letter are not significantly different at $P \leq 0.05$

Appendix 4: Effect of interaction between tillage and variety on plant height at flowering stage

	Katumani			Mwea		
Tillage	KS20	N26	Mean	KS20	N26	Mean
Conventional tillage	60.16b	54.83c	57.5	41.53c	36.98c	39.7
Furrow-ridge	73.72a	67.81a	70.77	57.10a	52.30a	55.18
Zero tillage	61.52b	58.33b	59.92	49.07b	42.77b	47.33
Mean	65.13	60.33		49.23	45.58	
LSD	2.215			4.181		
P Value	0.02			0.041		

LSD is least significant difference; means followed by same letter are not significantly different at P ≤ 0.05

Appendix 5: Effect of interaction of tillage, mulch and variety on number of branches

	Katumani				Mwea			
	Mulch (3 t/ha)		No Mulch (0 t/ha)		Mulch (3 t/ha)		No Mulch (0 t/ha)	
Tillage	KS20	N26	KS20	N26	KS20	N26	KS20	N26
Conventional tillage	4.0a	5.0b	3.0b	5.0a	4.0a	5.0a	3.0a	4.0a
Furrow-ridge	4.0a	6.0a	4.0a	5.0a	4.0a	5.0a	3.0a	4.0a
Zero tillage	4.0a	5.0b	3.0b	5.0a	4.0a	5.0a	3.0a	4.0a
Mean	4.31				4.00			
LSD	0.48				0.87			
P Value	0.001				0.62			

LSD is least significant difference; means followed by same letter are not significantly different atP ≤0.05

Appendix 6: Effect of interactions between tillage and Mulch on root biomass at flowering

	Katumani			Mwea		
		Mulch			Mulch	
Tillage	(3 t/ha)	(0 t/ha)	Mean	(3 t/ha)	(0 t/ha)	Mean
Conventional tillage	2.48b	1.36b	1.92	1.90a	1.17a	1.53
Furrow-ridge	2.91a	2.27a	2.59	2.20a	1.35a	1.77
Zero tillage	2.62b	1.43b	2.03	1.86a	1.27a	1.57
Mean	2.67	1.69		1.99	1.261	
LSD	0.25			0.307		
P Value	0.003			0.229		

LSD is least significant difference; means followed by the same letter are not significantly differentat P ≤ 0.05

Appendix 7: Effect of interaction between mulch and variety on root biomass at flowering

	Katumani			Mwea		
Mulch	KS20	N26	Mean	KS20	N26	Mean
(3 t/ha)	2.69a	2.65a	2.67	1.85a	2.12a	1.99
(0 t/ha)	1.63a	1.74a	1.69	1.26b	1.27b	1.26
Mean	2.16	2.20		1.986	1.26	
LSD	0.1199			0.1699		
P Value	0.072			0.044		

LSD is least significant difference; means followed by the same letter are not significantly differentat P ≤ 0.05.

Appendix 8: Effect of interaction of tillage and mulch number of nodules at floweringstage in Katumani and Mwea.

	Katumani Mulch			Mwea Mulch		
Tillage	(3 t/ha)	(0 t/ha)	Mean	(3 t/ha)	(0 t/ha)	Mean
Conventional tillage	22b	16b	19	18a	15a	17
Furrow-ridge	27a	20a	24	22a	17a	20
Zero tillage.	17c	15b	16	15b	13b	14
Mean	22	17		18	15	
LSD	2.0			2.4		
P Value	0.01			0.034		

LSD is least significant difference; means followed by the same letter are not significantly differentat P ≤0.05

Appendix 9: Effects of interaction between tillage and variety on number of root nodules at flowering stage

	Katumani Variety			Mwea Variety		
Tillage	KS20	N26	Mean	KS20	N26	Mean
Conventional tillage	22b	15b	18.58	18b	15b	17
Furrow-ridge	29a	19a	23.58	21a	18a	20

Appendix 10: Effect of interaction of tillage, mulch and variety on number of nodules at flowering stage in Katumani and Mwea

	Katumani				Mwea			
	Mulch (3 t/ha)		No Mulch (0 t/ha)		Mulch (3 t/ha)		No Mulch (0 t/ha)	
	Variety		Variety		Variety		Variety	
Tillage	KS20	N26	KS20	N26	KS20	N26	KS20	N26
Conventional tillage	26b	17b	18b	13b	19b	16a	16a	15a
Furrow-ridge	33a	21a	24a	17a	24a	20a	18a	15a
Zero tillage	19c	15b	16b	13b	16b	14a	15a	11a
Mean	19.31				17			
LSD	2.98				4.06			
P Value	0.003				0.05			

LSD is least significant difference; means followed by same letter are not significantly different at P ≤ 0.05

Appendix 11: Effect of interaction between tillage and variety on nodules mass at flowering in Katumani and Mwea

	Katumani			Mwea		
	Variety			Variety		
Tillage	KS20	N26	Mean	KS20	N26	Mean
Conventional tillage	0.051b	0.044b	0.047	0.048a	0.042a	0.045
Furrow-ridge	0.060a	0.050a	0.055	0.046a	0.038a	0.042
Zero tillage	0.043c	0.039c	0.041	0.041a	0.033a	0.037
Mean	0.051	0.044		0.045	0.038	
LSD	0.002			0.004		
P Value	<.001			0.744		

LSD is least significant difference; means followed by same letter are not significantly different atP ≤ 0.05

Appendix 12: Effect of interaction between mulch and variety on nodules mass at flowering

	Katumani			Mwea		
	Variety			Variety		
Mulch	KS20	N26	Mean	KS20	N26	Mean
(3t/ha)	0.055a	0.047a	0.051	0.051a	0.041a	0.046
(0 t/ha)	0.047b	0.042b	0.044	0.039b	0.034b	0.037
Mean	0.051	0.044		0.045	0.038	
LSD	0.002			0.004		
P Value	0.002			0.01		

LSD is least significant difference; means followed by same letter are not significantly different at P ≤ 0.05

Appendix 13: Effect of interaction between tillage, mulch and variety on nodule dry mass at flowering stage in Katumani and Mwea

	Katumani				Mwea			
	Mulch (3 t/ha)		No Mulch (0 t/ha)		Mulch (3t/ha)		No Mulch (0 t/ha)	
Tillage	KS20	N26	KS20	N26	KS20	N26	KS20	N26
Conventional tillage	0.054b	0.046b	0.047b	0.042b	0.052a	0.046a	0.044a	0.037a
Furrow-ridge	0.066a	0.053a	0.053a	0.046a	0.054a	0.040a	0.039a	0.035a
Zero tillage	0.046c	0.042c	0.040c	0.036c	0.047a	0.038a	0.035a	0.029a
Mean	0.048				0.041			
LSD	0.003				0.006			
P Value	0.034				0.17			

LSD is least significant difference; means followed by same letter are not significantly different at P ≤ 0.05

Appendix 14: Effect of interaction between tillage and variety on shoot biomass at flowering stage in Katumani and Mwea

	Katumani			Mwea		
	Variety			Variety		
Tillage	KS20	N26	Mean	KS20	N26	Mean
Conventional tillage	348.4c	404.7c	376.55	346.6a	368.5b	357.6
Furrow-ridge	431.2a	483.9a	457.55	367.8a	416.1a	329
Zero tillage	397.8b	430.3b		347.7a	391.3a	369.5
Mean	392.47	439.63		354.1	392	
LSD	14.65			31.97		
P Value	0.054			0.028		

LSD is least significant difference; means followed by same letter are not significantly different at P ≤ 0.05

Appendix 15: Effect of interaction between mulch and variety on shoot biomass at flowering

	Katumani			Mwea		
	Variety			Variety		
Mulch	KS20	N26	Mean	KS20	N26	Mean
(3t/ha)	420.6a	477.5a	449.05	377.9a	426.5a	402.2
(0 t/ha)	364.4b	401.8b	383.1	330.2b	357.4b	343.8
Mean	392.5	439.65		354.1	392	
LSD	12.77			19.67		
P Value	0.026			0.013		

LSD is least significant difference; means followed by same letter are not significantly different atP ≤0.05

Appendix 16: Effect of interactions of tillage, mulch and variety on shoot biomass at flowering(g/m^2) in Katumani and Mwea

	Katumani				Mwea			
	Mulch (3t/ha) Variety		No Mulch (0 t/ha) Variety		Mulch (3t/ha) Variety		No Mulch (0 t/ha) Variety	
Tillage	KS20	N26	KS20	N26	KS20	N26	KS20	N26
CT	388.6c	437.4c	308.2c	371.9c	367.9a	402.9a	325.3a	334.1
FR	454.9a	532.7a	407.6a	435.1a	388.3a	456.5a	347.3a	375.8
ZT	418.3b	462.3b	377.4b	398.4b	377.4a	420.2a	318.0a	362.3
Mean	416.1				373			
LSD	20.59				36.01			
P value	0.015				0.150			

LSD is least significant difference; means followed by same letter are not significantly different atP ≤0.05

Appendix 17: Effect of interaction between tillage and variety on number of pods per plant

	Variety			Variety		
Tillage	KS20	N26	Mean	KS20	N26	Mean
Conventional tillage	39c	42c	40.50	34b	42b	37.75
Furrow-ridge	56a	66a	60.75	39a	49a	44.25
Zero tillage	45b	50b	47.58	36b	44b	39.67
Mean	46.61	52.61		36.22	44.89	
LSD	2.66			2.18		
P Value	0.03			0.426		

LSD is least significant difference; means followed by same letter are not significant differently

Appendix 18: Effect of interaction of mulch and variety on number of pods per plant

	Katumani Variety			Mwea Variety		
Mulch	KS20	N26	Mean	KS20	N26	Mean
(3t/ha)	50.1a	57.2a	53.67	38.9a	49.3a	40.11
(0 t/ha)	43.1b	48.0b	45.56	33.6b	40.4b	37.00
Mean	46.61	52.61		36.22	44.89	
LSD	2.621			1.87		
P Value	0.031			0.013		

LSD is least significant difference; means followed by same letter are not significant at P ≤0.05

Appendix 19: Effect of interaction of tillage, mulch and variety on 1000 Seed weight

	Katumani				Mwea			
	Mulch (3t/ha) Variety		No Mulch (0t/ha) Variety		Mulch (3t/ha) Variety		No Mulch (0 t/ha) Variety	
Tillage	KS20	N26	KS20	N26	KS20	N26	KS20	N26
Conventional tillage	58.8c	55.6c	54.8b	53.0b	68.0b	64.7a	65.3a	58.0b
Furrow-ridge	75.4a	71.6a	70.5a	68.0a	75.3a	67.3a	68.7a	64.7a
Zero tillage	64.0b	60.6b	59.8b	56.8b	70.0b	64.7a	65.7a	59.3b
Mean	62.41				65.97			
LSD	2.714				5.32			
P Value	0.044				0.048			

LSD is least significant difference; means followed by same letter are not significantly different at P ≤ 0.05.

Appendix 20: Effect of interaction between tillage and variety on grain yield t/ha.

	Katumani			Mwea		
	Variety			Variety		
Tillage	KS20	N26	Mean	KS20	N26	Mean
Conventional tillage	0.89c	0.97c	0.93	0.89a	0.94a	0.91
Furrow-ridge	1.00a	1.17a	1.09	0.90a	1.02a	0.96
Zero tillage	0.95b	1.07b	1.01	0.85a	0.98a	0.92
Mean	0.95	1.07		0.88	0.98	
LSD	0.04			0.07		
P Value	0.02			0.23		

LSD is least significant difference; means followed by same letter are not significantly different at P ≤ 0.05

Appendix 21: Effect of interaction of mulch and variety on grain yield t/ha

	Katumani			Katumani		
	Variety			Variety		
Mulch	KS20	N26	Mean	KS20	N26	Mean
3t/ha	0.9959	1.155	1.0754	0.953	1.07	1.024
0t/ha	0.8974	0.9852	0.9413	0.806	0.885	0.846
Mean	0.9466	1.0701		0.88	0.97	
LSD	0.0342			0.005		
P Value	0.005			0.379		

LSD is least significant difference; means followed by same letter are not significantly different at P ≤ 0.05

Appendix 22: Effect of interaction of tillage, mulch and variety on yield t/ha

	Katumani				Mwea			
	Mulch Variety		No Mulch Variety		Mulch Variety		No Mulch Variety	
Tillage	KS20	N26	KS20	N26	KS20	N26	KS20	N26
Conventional tillage	0.95	1.00	0.82	0.91	0.96	1.00	0.81	0.87
Furrow-ridge	1.05	1.29	0.95	1.05	0.97	1.14	0.82	0.91
Zero tillage	0.99	1.14	0.92	0.99	0.93	1.07	0.78	0.89
Mean	1.01				0.929			
P Value	0.04				0.563			
LSD	0.05				0.0967			

LSD is least significant difference; means followed by same letter are not significantly different at P ≤ 0.05.

Appendix 23: Effect of interaction between tillage and variety on biomass at harvest t/ha

	Katumani			Mwea		
	Variety			Variety		
Tillage	KS20	N26	Mean	KS20	N26	Mean
Conventional tillage	3.031	3.218	3.125	2.84	3.2	3.02
Furrow-ridge	3.318	3.951	3.634	3.34	3.68	3.51
Zero tillage	2.943	3.497	3.22	2.76	3.18	2.97
Mean	3.098	3.555		2.98	3.35	
LSD	0.2081			0.21		
P Value	0.013			0.829		

LSD is least significant difference; means followed by same letter are not significantly different at P ≤ 0.05

Appendix 24: Effect of interaction between tillage, mulch and variety on shoot biomass at harvest in Katumani and Mwea

	Katumani				Mwea			
	Mulch (3 t/ha) Variety		No Mulch (0 t/ha) Variety		Mulch (3 t/ha) Variety		No Mulch (0 t/ha) Variety	
Tillage	KS20	N26	KS20	N26	KS20	N26	KS20	N26
Conventional tillage	3.3a	3.6b	2.7b	2.9b	3.2a	3.5a	2.5a	2.9a
Furrow-ridge	3.4a	4.3a	3.2a	3.6a	3.6a	4.2a	3.1a	3.2a
Zero tillage	3.2a	3.6b	2.7b	3.4a	2.9a	3.4a	2.6a	3.0a
Mean	3.33				3.16			
LSD	0.4				1.0			
P Value	0.05				0.21			

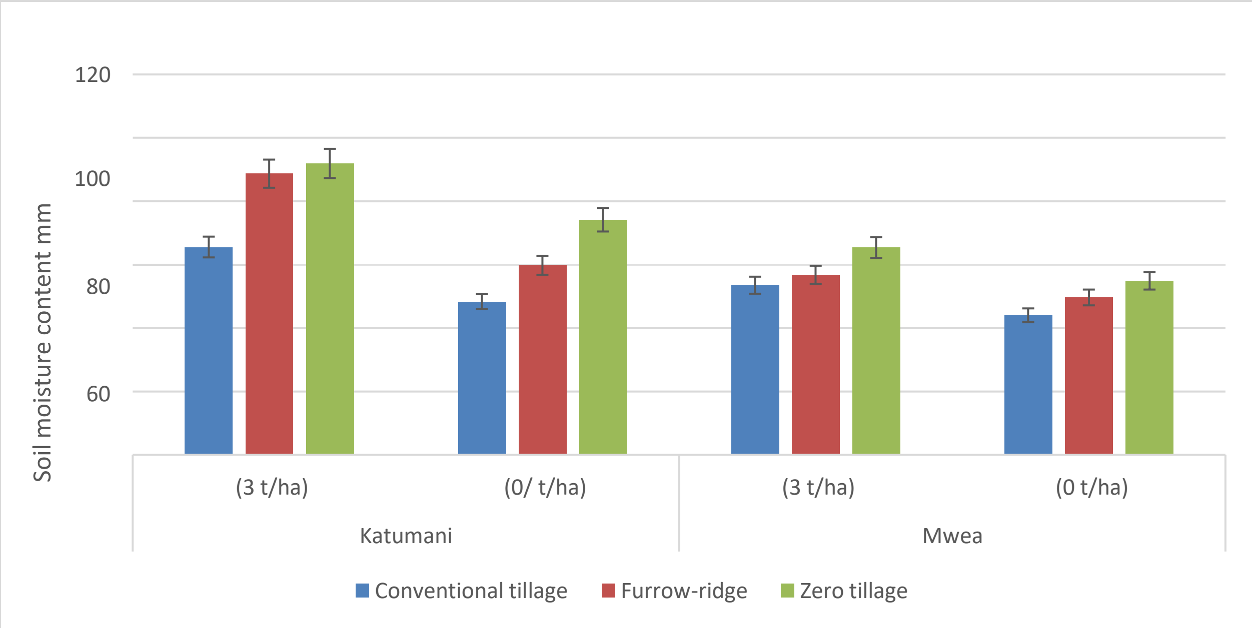
LSD is least significant difference; means followed by same letter are not significantly differentlyat P ≤0.05

Appendix 25: Effect of interaction between tillage, mulch and variety on harvest index in Katumani and Mwea

	Katumani				Mwea			
7l	Mulch Variety		No Mulch Variety		Mulch Variety		No Mulch Variety	
Tillage	KS20	N26	KS20	N26	KS20	N26	KS20	N26
CT	0.30c	0.29c	0.28b	0.32a	0.30a	0.30a	0.26a	0.28a
FR	0.31b	0.30b	0.30a	0.30b	0.32a	0.30a	0.27a	0.28a
ZT	0.35a	0.32a	0.30a	0.30b	0.34a	0.31a	0.30a	0.29a
Mean	0.31				0.30			
LSD	0.01				0.20			
P Value	0.027				0.789			

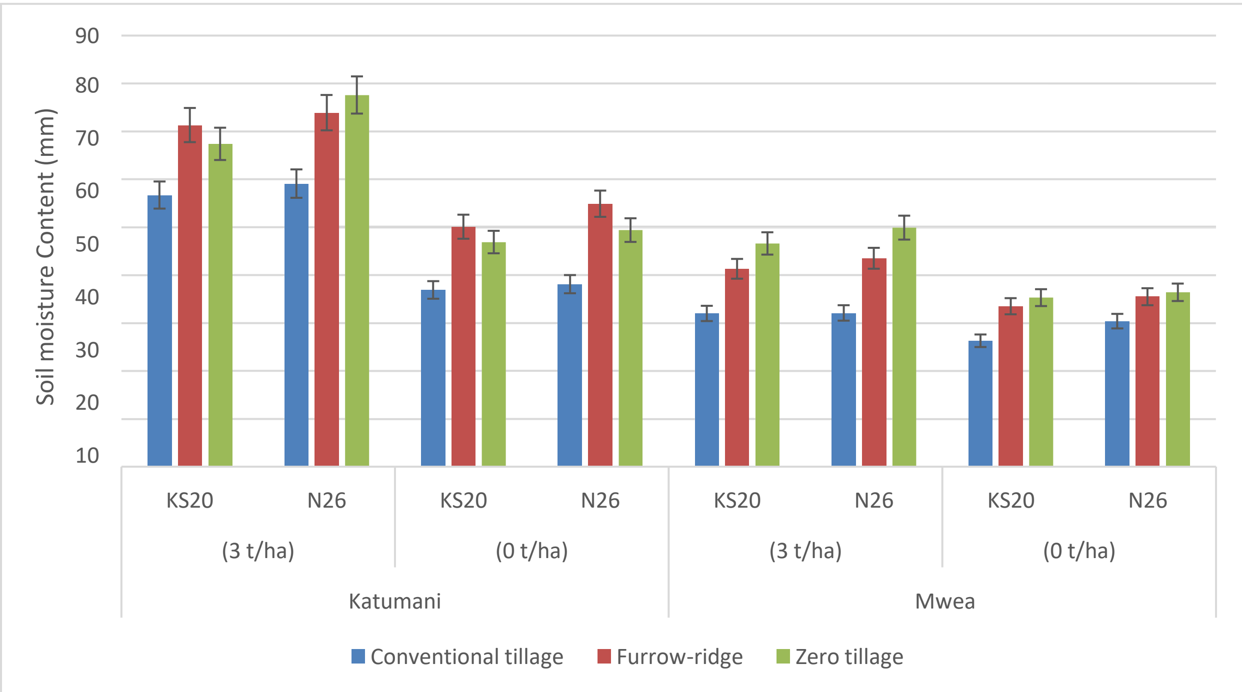
LSD is least significant difference; means followed by same letter are not significantly differently at P ≤0.05

Appendix 26: Effects of interaction of tillage, mulch and variety on soil moisture at vegetative stage (30 DAP)



Error bars show standard error of mean

Appendix 27: Effects of interaction of tillage, mulch and variety on soil moisture at flowering stage (40 DAP)



Error bars show standard error of mean