# RESPONSE OF SELECTED GREEN GRAM (*Vigna radiata*) VARIETIES TO VARYING MOISTURE REGIMES AND ADAPTATION TO NO-TILLAGE WITH RESIDUE RETENTION

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**UNIVERSITY OF NAIROBI**

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

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This thesis has been submitted with our approval as university supervisors.

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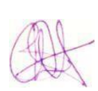
Signature:  Date: 30/11/2023

## DEDICATION

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# ABBREVIATIONS AND ACRONYMS

| | |
|---|---|
| ASALs | Arid and Semi-Arid Lands |
| CA | Conservation Agriculture |
| CSA | Climate Smart Agriculture |
| FAO | Food and Agriculture Organization of the United Nations |
| FC | Field Capacity |
| KALRO | Kenya Agricultural and Livestock Research Organization |
| KCSAP | Kenya Climate Smart Agriculture Project |
| LSD | Least Significant Difference |
| RUE | Radiation Use Efficiency |
| SPAD | Soil Plant Analysis Development |
| SSA | Sub Saharan Africa |
| USAID | United States Agency for International Development |
| WUE | Water Use Efficiency |

# GENERAL ABSTRACT

Green gram (*Vigna radiata* L.) is a hard pulse well adapted to marginal areas. Moisture stress is considered the most limiting factor in green gram production resulting to low yields experienced by farmers. With climate change bound to worsen the situation, soil moisture conservation strategies with minimum soil disturbance, for instance, no-tillage system could be adopted by farmers to ameliorate the situation. Despite breeding advances to adapt green gram to drought, mechanisms regulating responses to moisture stress are only partially understood. In addition, evidence on the adaptation of green gram to no-tillage and residue retention systems is limited.In the backdrop of the existing gaps in knowledge, both greenhouse and field experiments were conducted to: (a) evaluate response of selected green gram varieties to varying moisture regimes, and (b) determine the response of selected green gram varieties to no-tillage system. Greenhouse trials were conducted at University of Nairobi, Kabete field station. Treatments comprising five selected green gram varieties N26, KS20, Biashara, Karembo and Ndengu Tosha and four moisture regimes of 40%, 60%, 80% and 100% field capacity (FC) were laid out in randomized complete block design. Field experiments were conducted in Machakos county of Southern Kenya at KALRO Katumani and in a farmer's field in Kikesa village. Treatments consisting of two tillage systems (no tillage and conventional tillage) and five selected green gram varieties (N26, KS20, Karembo, Biashara and Ndengu Tosha) were laid out in randomized complete block design with a split plot arrangement. Tillage systems were assigned to main plots while varieties formed the subplots. In the first objective, days to 50% branching, flowering, podding and maturity were determined, as well as corresponding number of nodules, active nodules and nodules dry mass. Plant height and leaf greenness were measured at branching and flowering. Root length, root angle and root dry mass were also measured at branching and flowering. At physiological maturity number of pods per plant were recorded. At harvesting, data on number ofseeds per pods, pod length and seed yield were measured. In the second objective, crop phenology and crop growth traits of selected green gram varieties under the two tillage systems were measured. Generally, the five selected green gram varieties varied significantly ($P<0.05$) under four moisture regimes and tillage systems. Variety N26 was late maturing while the other four varieties were intermediate in number of days to maturity. Additionally, N26 also had the highest number of total nodules and active nodules under four moisture regimes and no tillage system. Green gram varieties grown under 60%, 80% and 100% FC were greener and produced agreater number of pods and yield compared to crops in 40% FC.

While the varieties did not show any significant difference in root length and root angle, significant differences $P<0.05$ in seed yield were recorded among the varieties as well as the moisture regimes. In objective two, selected varieties varied significantly $P<0.05$ in phenology, crop growth traits and yield. However, no significant differences were recorded between conventional tillage and no tillage systems; this ascertains that breeding of green gram varieties in Kenya has not selected for response of green gram varieties to no tillage system. Although N26 performed better compared to other varieties in both experiments, more attention should be focused on the recently released varieties with early maturity trait. Results of this study imply that evaluation of released green gram varieties to varying moisture regimes and no tillage system could facilitate adoption of soil moisture conservation measures by farmers to achieve higher yields and curb climate change challenges.

# CHAPTER ONE: INTRODUCTION

## 1.1 Background information

Grain legumes have been in existence and cultivated by farmers since ages. They provide nutritious as well as balanced food to many people in different countries all over the world (Kumar and Pandey, 2020). Key among the most important grain legumes in dryland regions of Kenya is green gram also referred to as mungbean. This legume is an essential early maturing legume with broad adaptability to diverse agroecological zones, minimal input requirement and capacity to improve soil fertility through biological nitrogen fixation (Kebede, 2021). Green gram is now grown on more than 6 million ha worldwide which accounts for 8.5% of the global pulse production (Noble et al., 2020). Production of green gram is mainly situated in Asia with India producing largest quantities of more than 50% worldwide (Masaku, 2019).

Green gram has demonstrated its ability to thrive in drier areas of Kenya, for example, Machakos, Kitui and Tharaka Nithi due to its trait of early maturity (Mugo et al., 2020). These regions have not been able to produce enough to meet growing demand of green gram in the country as a result of an increase in consumption due to preference by consumers compared to other legumes (Muriithi, 2020). Green gram production has therefore expanded and non- traditional regions have started to grow it; among the regions are Baringo, Isiolo, Taita Taveta, West Pokot and Tana River.

Recently, the country registered over 60% increase in acreage of green gram from 188,000ha in 2012 to over 302,000ha in 2017 (Mugure et al.,2023). Nevertheless, Kenya imported about 14,000 metric tons annually from Uganda and Tanzania to meet her domestic demand (Masaku, 2019). Currently farmers harvest less than 0.5t/ha against a yield potential of 4t/ha (Mugure et al., 2023). This yield gap could be attributed to lack of improved varieties, low water and nutrient use efficiency, pest and diseases, and poor post-harvest technology (Mulwa et al.,2023).

It has been reported that drought is the major limitation to expanding agricultural productivity in Kenya (Kalele et al., 2021). Low and highly erratic rainfall results to frequent droughts which pose a great challenge to farmers. Inadequate water affects nutrient uptake by the plants from the soil leaving plant cells less turgid therefore contributing to stunted growth of plants as well as low yields (Ahmed et al., 2020).

Green gram just like any other legume is commonly grown in rainfed regions in Kenya. Increase in the intensity as well as frequency of drought as predicted pose a risk of scarcity of water (Mugure et al., 2023). Moisture stress experienced at any particular stage of plant growth may result in reduction of crop production basically during the reproductive phase and grain filling (Dutta et al., 2022). Frequency of drought as well as severity limit plant biomass partitioning and accumulation, yield and other related components (Kapoor et al., 2020). The extent of yield reduction could depend on duration and intensity of drought stress. Therefore, to increase green gram yield under increasingly variable weather conditions, and in particular low and poorly distributed rainfall, climate-resilient crop management practices are crucial.

Climate smart agriculture through adoption of conservation agriculture, minimum soil disturbance, no tillage system and residue retention are strategies that aim at improving plant growth and yield production in ASALS. No-tillage with residue retention system conserve water that could have been lost through evaporation and run off. Despite advances in the development of drought tolerant varieties by plant breeders there is limited knowledge on how these varieties respond to varying moisture regimes, no-tillage system with and residue retention.

### 1.2 Statement of the problem

Drought poses a significant threat to global crop production, disrupting essential plant processes such as carbon assimilation and turgor maintenance (Ahmad et al., 2022). The escalating frequency and intensity of drought in regions cultivating green gram underscore the urgency of selecting resilient varieties. However, comprehensive insights into the traits and mechanisms governing green gram's adaptation to diverse moisture regimes and no-tillage practices with residue retention remain scarce. Conservation agriculture, including no-tillage systems and residue retention, emerges as a viable strategy for drought management, yet the specific responses of green gram varieties to varying moisture levels and these conservation practices remain inadequately understood.

### 1.3 Justification of the study

Drought and moisture stress stand as the most limiting factors affecting green gram production, significantly impeding its yield potential. As an indispensable pulse crop of substantial nutritional and economic value (Wambua, 2021), the escalating demand for green gram, both domestically and globally, accentuates the imperative to enhance its yield. Bridging the existing yield gaps serves as the primary strategy to augment green gram production, catering to rising demands and fostering economic opportunities. Amidst the challenges posed by climate change, characterized by recurrent droughts and erratic rainfall patterns, the adoption of climate-smart agricultural practices emerges as pivotal. Strategies focusing on moisture conservation and minimizing soil disturbance assume critical significance in mitigating these challenges. Response of green gram varieties to moisture stress and adaptation no-till with residue retention is partially understood thus a subject of this study. The findings of this study will benefit scientists on understanding how different green gram varieties respond to varying moisture regimes, no-tillage system with residue retention as well as aid in the development of varieties that are drought tolerant. Farmers will also have a better choice of green gram varieties based on the response to moisture stress, no-till and residue retention.

### 1.4 Objectives

The broad objective of this study is to increase green gram yield through understanding the mechanisms regulating crop development and yield formation under contrasting soil moisture regimes, and tillage systems. The study was conceived with the following specific objectives:

1. To determine the response of selected green gram varieties to varied moisture regimes
2. To evaluate the response of selected green gram varieties to no-till with residue retention

### 1.5 Hypotheses

1. Green gram varieties do not respond differently to varied soil moisture regimes
2. Green gram varieties do not respond differently to no-till and residue retention systems

# CHAPTER TWO: LITERATURE REVIEW

## 2.1 Botany and ecology of green gram

Green gram is an annual, erect or semi-erect plant, which grows to a height of 15-120 cm (Nirmala et al., 2023). Green gram is hairy to some extend with well-developed tap root system. The leaves arrangement is alternate, trifoliolate with ovate shape, 5-12 cm long and 3-10 cm broad. The color of flowers is pale yellow. Pods are long with cylindrical shape containing 10 to 20 small cube-shaped seeds which are bright to pale green in color. Green gram is an early maturing, warm-season legume. It matures faster under conditions with optimum temperature of about 28- 30°C above 15°C. One of the most important things about green grams is that it does not require too much water since it can tolerate drought. High moisture content at maturity is capable of spoiling the seeds and may cause them to sprout before harvest time. Green gram is adaptable to awide diversity of soils but preferably, well-drained loam or sandy loams with pH ranging from 5 to 8.

## 2.2 Importance and utilization of green gram in Kenya

Green gram is regarded to be better in terms of food quality compared to other pulses (Masaku, 2019). Green gram can be consumed when whole and dry, either cooked or milled or prepared into varied categories of dishes among them are noodles, snacks, soups, porridge even bread (Nasir et al., 2022). The Asian community in Kenya is the biggest consumer of this grain legume, and normally cook it as split grains. Additionally, green gram is sometimes grown for the purpose of cover cropping and hay (Mulika, 2022).

Green grams also act as a green manure crop by enriching soil with nutrients through biological nitrogen fixation in the root nodules and improving soil structure (Masaku, 2019). The heavy leaf protein increases soil organic matter, tap root system opens the soil into deeper strata. As an early maturing crop, green gram is convenient in many intensive crop rotation systems (Mulika, 2022). It can also be used as livestock feed; plants are harvested when green through uprooting or cutting at the base, chopped and fed to livestock. After harvesting and threshing the crop, the husks are also stored and become feed to livestock during periods of forage shortage. The husks can be soaked in water, afterwards fed to livestock (Banker et al., 2020)

## 2.3 Green gram production trends in Kenya

Green gram is considered as one of the legumes that can thrive well in arid and semi-arid lands (ASALs). Nonetheless, change in climate is expected to consequently alter the areas useful for green gram production. ASALs cover about 80% of total area in Kenya mostly coastal, eastern and northern regions (Ondiko and Karanja, 2021). Rainfall received in these regions is bimodal with short rains between October and December while long rains between March and May (Ondiko and Karanja, 2021. Crops require adequate amount of water during the critical stages of germination, flowering and grain filling (Dietz et al.,2021). Unfortunately, rainfall received in these regions normally are erratic and quite unreliable, resulting to unfavorable distribution leading to low yield as compared to potentialyield (Mugure et al., 2023). However, the demand of the crop is increasing as a result of the growing population and higher market prices compared to other legumes (Mugure et al., 2023).

Recently, the country registered over 60% acreage increase under green gram production from 188,000 ha in 2012 to over 302,000 ha in 2017 due to expansion to non-traditional growing areas (Masaku, 2019). Nevertheless, Kenya imported about 14,000 million tons annually from Uganda and Tanzania to meet her domestic demand. (Mugure et al., 2023). Currently, farmers harvest less than 0.5 t/ha against a yield potential of 4t/ha (Mugure et al., 2023). This yield gap could be as a result to lack of improved varieties, low water and nutrient use efficiency, pest and poor post-harvest technology (Muriithi, 2020). To mitigate against these low yields experienced as a result of moisture stress, climate smart strategies such as conservation agriculture which entail minimal soil disturbance and residue retention could be adopted by farmers.

## 2.4 Constraints to green gram production in Kenya

Green gram being a low input crop faces production challenges in Kenya. There are several constraints that limit farmers from acquiring potential yield. It has been reported that drought is among main constraints limiting agricultural productivity in Kenya (Kalele et al., 2021). Rain has become unreliable as well as highly erratic resulting from climate change. Therefore, an urgent call to come up with agronomic strategies that would assist farmers to stabilize their production.

Additionally, farmers practice intensive ploughing during land preparation using hoe and machinery as well as burning or removal of crop residues which exposes the land to climate risk leading to land degradation (Micheni et al., 2022). Conservation agriculture incorporates minimum soil disturbance, cover cropping and diverse rotation, this contributes to sustainable cropping system that conserve soil moisture (Oduor et al., 2021). Rapid change in the incidence and manifestation of weeds, pests and diseases are major challenges facing small-scale farmers. This calls for farmers to adopt good agronomic practices.

### 2.5 Adaptation of green gram to moisture stress

Green gram responds to moisture stress by either avoidance, escape and tolerance. Drought alters certain several traits in the growth and development of legumes these include germination, root and shoot development as well as photosynthesis (Ullah and Farooq, 2022). Based on various studies it is evident that severe drought could interfere with plant morphology, growing period and physiology while moisture play a big role in enzyme activation throughout germination which can help in depicting susceptibility of crops to drought during germination (Kapoor et al., 2020). In legumes, such as soybeans, water deficit impacts two critical stages: germination and reproduction. Notably, drought stress significantly reduces the germination rate in soybeans (Poudel et al., 2023). Drought escape is reported as primary adaptation mechanism in green gram. It involves accelerated crop growth and development to aid completion of plant duration through early maturing before drought sets in (Masaku, 2019). Legumes escape drought through early flowering and reaching physiological maturity faster to avoid stress. This can be achieved by retaining water in the tissues through improving water uptake and reducing water loss (Khatun et al., 2021). Plants with deep rooting system are in a better position to withstand moisture stress compared to other plants that are shallow rooted (Rao et al., 2021). Nonetheless, if drought is experienced duringthe earlier stages of growth and development, plants with drought escape mechanisms can gradually switch to drought avoidance with progressive drought tolerance mechanism such as osmolytes production as well as effective water use efficiency (Kapoor et al., 2020).

### 2.5.1 Breeding advances in green gram in Kenya

Legumes are considered second most essential to humans after cereals. In spite of the fact that the productivity of legume is 50% less than cereals, legumes fetch higher returns in global markets (Wani et al., 2021). Regrettably, while cereal crop yields have seen significant advancements, the progress in enhancing legume crop yields has been slower. Breeding approaches have had limited success in tackling the issue of low productivity in certain legumes, falling short of the desired pace of improvement. Therefore, it is very vital to intensify legume enhancement programs. Rapid changes are experienced globally resulting from climate change creating a huge threat to food security.

Abiotic stress has been considered a major hindrance to crop production among them are drought, salinity, and heat causing an enormous impact on agricultural productivity (Masaku, 2019). Adaptation of green gram varieties to moisture stress due to their traits and mechanisms is an important aspect to plant breeders in advancement of different varieties as well as development of drought tolerant varietiesadaptable to different ecological zones. The response of crops to these stresses is important in considering management options. In Kenya plant breeders have continually improved the green gram varieties on the aspect of drought tolerance and escape as well as released early maturing green gram which takes 60-90 days to mature. Many factors strongly related with drought tolerance in legumes include the root architecture which is the most assuring trait for drought escape as well as useful in the breeding program for drought tolerance. Under Arid and Semi-arid Lands Agricultural Productivity Research Project, KALRO recently developed and released three varieties Karembo, Biashara and Ndengu Tosha that are early maturing, with greater than 20% yield advantage over the old varieties such as N26 and KS20.

### 2.5.2 Agronomic strategies for green gram adaptation to moisture stress

Evidence suggests that yield formation is a function of breeding and agronomy, where agronomic practices contribute about 70% and breeding about 30%. Inadequate moisture is considered as a huge limitation in crop production in Kenya (Oduor et al., 2021). Low yield can be associated to the limited availability of water to the crop as a result of rainfall variability, water loss through evaporation and immanent low levels of soil nutrients. To fulfil the rising food demand while minimizing water consumption, future farming systems must prioritize high water use efficiency.

Crop management practices such as tillage, seed quality, time of sowing, optimum seed rate; mulching, plant nutrition, weed management and irrigation facilitate greater opportunities in mitigating moisture stress in green gram production. Conservation tillage system is one of the practices towards conserving soil moisture. This could help to overcome biotic and abiotic stresses in legumes. No- till technique could result to positive impact in crop production as well asminimize soil degradation and soil erosion in legumes (Hussain et al., 2021). Conservation agriculture aims at conserving soil water retention. This can be attained through improving crop water use efficiency (WUE) through minimum tillage to minimize water lost via evaporation from exposed clods.

**2.6 Traits influencing growth and yield of green gram under moisture stress and no till**

To boost the agronomic strategies for the adaptation to moisture stress there are traits that influence growth as well as yield of green gram under moisture stress and no till. Moisture stress has an impact on crop phenology, leaf area development and biomass accumulation. Different plant species manifest their great variation in the final harvestable yield under drought stress but thereafter they all result to lower yield (Talwar et al., 2020). Majority of plant species, plant growth, biomass accumulation and partitioning, harvestable yield is greatly affected by drought stress, even though the level tolerance by any plant species to this peril vary remarkably. Proliferate root system that contribute to increase in biomass production have been involved in thedrought tolerance because of ability to absorb water from beneath and transport it to aboveground for photosynthesis purpose.

On the other hand, observed change in photosynthetic pigments is paramount and of importanceto drought tolerance. Among the root traits, root length, tap root system, rooting depth and densityare promising factors for drought stress avoidance in legumes such as common bean, chickpea and cow pea and may be of great importance for screening genotypes for drought tolerance (Basu et al., 2022). Traits such as early maturity, early branching, flowering, and podding offer an escape mechanism and could significantly contribute to mass screening processes. (Kumari et al., 2021). Cool canopies in addition to high stomatal conductance are traits that provide for indirect selection and have been associated with high grain yield under drought (Masaku et al., 2019).

## 2.7 Conservation agriculture defined

As a result, to increased soil degradation conservation agriculture is currently adopted in many parts of the world thus sustainable agriculture. Conservation agriculture is defined as a practice that entail minimum soil disturbance, permanent soil cover combined with crop rotations and intercropping (Farooq et al., 2020). Conservation agriculture (CA) was proposed to be remedy to agricultural challenges faced by smallholder farmers in the tropics (Farooq et al., 2020). It precisely aims at addressing the dilemma of soil degradation as a result of intensive agricultural practices that end up depleting organic matter in the soil and nutrient content, moreover, it purports to address question of intense labor requirement by smallholder farmers.

Major advantages of conservation agriculture that have been reported comprise reduced soil erosion that may result from wind and water, increasing efficiency of water use through advanced infiltration and retention mechanisms, increasing nutrient use efficiency through advanced fertilizer placement methods and nutrient cycling practices, diverse soil biology and increased soilorganic matter (Micheni et al., 2022). Legumes are considered best crops for use while practicing conservation agriculture since they can be used both as soil cover crop and rotation component. Major benefit of legumes is the ability to fix nitrogen in the soil while conserving existing nitrogen reserves without depleting it (Hakim et al., 2022)

### 2.7.1 Adoption and future prospects of conservation agriculture in legumes systems

Conservation agriculture is currently advocated for in Africa as an alternative approach to increase food production due to high demand as a result of increased population as well as currently experienced changes of weather patterns believed to be as a result of climate change. It focuses on more sustainable agricultural practices (Hakim et al., 2022). It is precisely viewed as means of addressing soil degradation challenges that deplete nutrient content and organic matter in the soil. This strategy focuses at achieving high crop yields with low production cost. Nonetheless, success of adopting CA by farmers in Africa has been limited (Autio et al., 2021).

Adoption of CA by farmers in Kenya is not only low but rather practiced majorly by local and international organizations such as FAO and KALRO (Wangithi et al., 2021). Several factors that have been identified as limiting factors to adoption as well as effectiveness of CA in Kenya and Sub-Saharan Africa (Autio et al.,2021). Many farmers lack adequate knowledge on CA as well as patience since it can take some time before one realizes high yields and the benefits.

### 2.8 The yield physiology of green gram

Green gram is a low input plant that is adaptable to low moisture but severe drought can result to crop failure. Crop growth and establishment is so crucial as well as determines the yield. Number of plants and the spacing between the rows is important factor to consider. Green gram should be sown on the onset of rain, dry planting could result failure to emerge. Major challenge that has resulted to low yields by farmers in Kenya is severe drought, lack of agronomic skills, pest and diseases as well as post-harvest losses (Mulwa et al., 2023). Moreover, factors determining the yield of green gram include crop phenology, biomass accumulation, and crucial yield components, all playing pivotal roles.

#### 2.8.1 Green gram phenology

The essential determinant of yield as well as yield potential in green gram is the time taken from sowing to maturity since it enables the plants to match the developmental process. It also helps in the determination of how the crop fit into the varying cropping systems as well as timing of the field operations along with harvesting. The time taken by the crop to mature differ based on the changing weather conditions in the agroecological zones as well as sowing time and seasons. Consequently, the ability to determine the duration of a crop plays an important role in understanding along with addressing the cause of variability of yield in green gram (Mulwa et al., 2023).

Green gram is a short-day plant whereby the estimated process towards flowering can be illustrated by employing a set of linear models to merge the effects of temperature and photoperiod (Masaku et al., 2018). There are different growth stages that leads to flowering. These stages consist of time of sowing to emergence, emergence until end of vegetative phase, a photoperiod-induced phase which ends at flower initiation, and flower development phase which ends at 50% flowering. Following flowering, green gram plant undergoes slower phase before the onset of grain filling phase, followed by period between grain filling and physiological maturity, harvest-ripe period and finally grain harvest (Guna et al., 2022).

### 2.8.2 Biomass accumulation and partitioning

The most important yield determinant factor in green gram is biomass also known as dry matter. It accounts to over 90% of the total green gram yield variation (Geetika et al., 2022). Biomass accumulation can be described as a utility of leaf area index, duration and interception of light, along with RUE. It has also been recorded that increase of plant density plants/$m^2$ may increase the leaf area and on that account increase biomass. Despite large leaf area, a significant threat arises in the later stages as it can lead to water deficits. Green gram RUE of 0.94 g/MJ corresponds to that of cowpea and soybean, as a consequence this paradigm is not affected by soil moisture (Geetika et al., 2022). Regardless of various strategies sought to increase biomass accumulation, the resultant increase in yield is likely to vary substantially. Increasing biomass production in green gram can be achieved through ensuring early attainment of a critical leaf area index of 3-4, coming up with plants that poses narrow leaflets to allow effective distribution of light within the green gram canopy as well as increasing crop duration (Masaku et al., 2018). This is because biomass partitioning in green gram is a function of water availability and use, which often vary remarkably. The efficiency of biomass partitioning is represented by harvest index which can be described as ratio between yield and total above ground biomass.

### 2.8.3 Radiation capture and use efficiency

Under favorable conditions, yield quantity attained by a crop corresponds with the solar radiation, photosynthetic active radiation (PAR), intercepted by the crop (Dhakar et al., 2023). Linear regression between biomass and cumulative radiation intercepted by a crop has been used to determine RUE (Saha et al., 2022).

Radiation use efficiency is of importance since it can be used in evaluation of crop performance as well as determination of yield limitations in different climate conditions (Masaku et al., 2018). Green leaf area as well as duration in addition to canopy extinction coefficient (K) influence radiation interception which is a variable throughout the period of crop growth.

### 2.8.4 Yield assessment period in green gram

In addition to agronomic practices that aims at improving yield in green gram such as the row and interplant spacing as well as weeding and other field management practices, there are two stages that are crucial in yield determination of green gram. The period between branching and flowering is critical phase for green gram (Kumar et al.,2020). Management practices ought to maximize crop growth during this period by reducing moisture, nutritional and other growth limitations. Branches per plant as well as flowering in green gram are essential components since they both show correspondence to pods per plant. Increase in pods per plant corresponds with the number ofseeds and hence increasing the yield. During flowering stage, excessive rainfall poses a threat to green gram and can result to flower abortion, reducing the number of flowers as well as a challenge to expected grain yield. On the other hand, also, severe drought is a challenge to both branching and flowering which will thereafter have a negative effect on the pod filling and the grain (Mugo et al., 2023)

### 2.8.5 Water and nutrient uptake

The yield of green gram is intricately tied to both water availability and nutrient uptake processes. Studies, such as Mugo et al. (2023), have highlighted the pivotal role of initial plant-available water and in-crop rainfall in determining the crop's productivity. Particularly in dryland conditions, the water use efficiency of green gram hovers around 5–6 kg of grain per millimeter of water, underscoring its sensitivity to moisture availability. Notably, as a legume capable of biological nitrogen fixation, green gram possesses a unique advantage in utilizing fixed nitrogen for its growth. This inherent ability not only aids in the legume's development but also minimizes the necessity for extensive fertilizer application. Consequently, it has the potential to leave residual nitrogen in the soil, benefiting subsequent crops (Kebede, 2021).

However, while water is crucial for its growth and yield, excess water or waterlogging can negatively impact green gram. In dryland regions where plant access to water is restricted, the challenge of nutrient uptake becomes pronounced, ultimately exerting a detrimental influence on yield (Mugo et al., 2023). Therefore, the comprehensive understanding of water availability, nitrogen fixation, and the delicate balance of nutrient uptake becomes crucial in maximizing the yield potential of green gram in varying environmental conditions.

### 2.8.6 Yield and yield components of green grams

The interrelation of yield and components of yield is essential for selection of desirable traits for a particular environment. Yield components in green gram that contribute to yield include number of pods per plant, pod length, seeds per pod as well as 100 grain weight (Salman et al., 2023). The weight of the grain strongly corresponds with length and width of the pods while pods per plant is significantly associated with branches per plant (Bavyasri et al., 2022). Days to branching, flowering and podding, pods per plant and seeds per pods are contributing factors to yield in green gram production.

# CHAPTER THREE: RESPONSE OF SELECTED GREEN GRAM VARIETIES TO VARYING SOIL MOISTURE REGIMES

## 3.1 Abstract

Green gram is increasingly becoming an important food crop and source of income in sub- Saharan Africa. Relatively high demand as well as nutritional value has resulted to expansion in production of this legume to non-traditional areas of Kenya but present yields oscillate around 0.5 t/ha compared with yield potential of about 4 t/ha. Despite green gram being drought tolerant, low yields result from moisture stress, in addition to low soil fertility, pests and diseases. The selection and deployment of drought tolerant green gram varieties might face constraints due to lack of comprehensive understanding regarding mechanisms that regulate how green gam respond to moisture stress. A controlled environment study was conducted to evaluate the response of five Kenyan green gram varieties to varying moisture regimes. The green gram varieties comprised two old varieties, N26 and KS20, both released in 1990s and three modern counterparts consisting of Karembo, Ndengu Tosha and Biashara which were bred in 2017. The varieties were subjected to four soil moisture regimes of 40%, 60%, 80% and 100% field capacity. Owing to substantial shading effects in the greenhouse, factorial combinations of variety and field capacity were set in a randomized complete block design, replicated three times, for two experimental cycles. Crop growth traits andyield components were collected and subjected to analysis of variance using GenStat at 5% probability level. In both experiments, the five green gram varieties varied significantly in phenology whereby N26 matured late at 70 days after emergence compared with the rest of varieties whose maturity ranged between 60-63 days. Differences among the varieties were measured in number of nodules with N26 and KS20 recording high number of nodules per plant, 16 and 15, respectively. Significant differences in plant height, leaf greenness, number of pods perplant, pod length, number of seeds per pods and seed yield were recorded. Variety N26 was the tallest 38 cm followed by KS20 35 cm while Biashara was the shortest with 30 cm. Additionally, N26 had highest number of pods per plant, pod length, seeds per pod as well as high yield of 28 g/plant. Significant effects of soil moisture regime on green gram growth and yield were measured. Under 40% field capacity low yield of 14 g/plant was recorded, at 60%, 80% and 100%field capacities the yields recorded were 26 g/plant, 28.1 g/plant and 24 g/plant respectively. Root traits entailing root length, root angle and root mass did not show any significant differences

among the varieties and soil moisture regimes. Results did not reveal significant interactions between variety and moisture regime, which suggests that the breeding programs in Kenyan green gram have not selected for enhanced response to moisture stress. Nevertheless, breeding programs could select for early maturity and higher yield.

**Key words:** selection, drought, tolerance, moisture stress,

### 3.2 Introduction

Green gram (*Vigna radiata*) is an early maturing legume that has broad adaptability to diverse agroecological zones, minimal input requirement and ability to boost soil fertility through biological nitrogen fixation (Kebede, 2021). Currently, this legume is grown on more than 6 million ha worldwide, accounting for 8.5% global area under pulses (Noble et al., 2020). In Kenya, green gram is grown on more than 302,000 ha, mainly by small scale farmers under rainfed conditions with 90% of production concentrated in the drier areas of Machakos, Mbeere, Makueni, Meru, Kitui and Tharaka counties (Mugo et al., 2021). In spite of being an important legume in Kenyan ASALs, its grain yield remains low. Recent reports show decrease from 0.50 t/ha to 0.49 t/ha in 2013 and 2017, respectively (Kilimo Trust 2017). Increases in green gram acreage and production by 61% and 62% in 2012 and 2018, respectively, have not been a success in meeting the growing domestic demand (Mugure et al.,2023). A recent report shows that farmers harvest less than 0.5t/ha against a yield potential of 4 t/ha (Karimi et al., 2019). This yield gap is ascribed to lack of improved varieties, low water and nutrient use efficiencies, pests and diseases, and poor post- harvest technology. It has been reported that drought is the major limitation to expanding agricultural productivity in Kenya (Muriithi, 2020).

Low and highly erratic rainfall results to frequent droughts which pose great challenge to farmers. Inadequate water affects nutrient uptake from the soil to plant cells leaving plant cells less turgid thus contributing to stunting (Ahmad et al., 2022). Green gram, like most legumes, is commonly grown in rainfed regions in Kenya. Increase in the intensity as well as frequency of drought as predicted pose a risk of scarcity of water (Ahmad et al., 2022). Moisture stress experienced during crop growth especially at flowering in green grams may result to reduction of crop production basically during the reproductive phase and grain filling (Dutta et al., 2022).

Frequency and severity of drought limits plant biomass accumulation and partitioning, yield and other related components (Kapoor et al., 2020). The level of yield reduction could depend on duration and intensity of drought stress. Therefore, to bridge the yield gap that is currently experienced in green gram production, drought tolerant varieties of green gram should be adopted by farmers to achieve increased yield.

Recurrent and prolonged droughts currently experienced in agricultural production have resulted to significant yield losses in many crops. Substantial efforts to curb this challenge through innovative research, development of techniques and methodologies in drought resistance breeding are key. Breeding has been done towards achieving early maturing and drought tolerant green gram varieties with a higher yield potential. Karembo, Biashara and Ndengu Tosha varieties recently released by KALRO, takes less than 90 days to mature. Despite advances in green gram breeding, knowledge on response of these varieties to moisture stress is limited.

Increasing demand for green gram, both locally and internationally intensifies the need to increase yield. Reduction of the existing yield gaps is the main strategy for increasing green gram yield for income generation as well as meeting the high demand. The objective of this research is to evaluate the response of green gram varieties to varying soil moisture regimes. The study hypothesized that green gram varieties do not respond differently to varied soil moisture regimes.

## 3.3 Materials and methods

### 3.3.1 Greenhouse experiment

Greenhouse trials were conducted at the field station of University of Nairobi, Kenya. The experiment was carried out in two cycles between October 2020 and March 2021. Kabete field station lies $0^{o}14'45''$S, $36^{o}44'19''$E and 1940 m above the sea level. The agro-ecological classification of Kabete is upper midland zone III (Ndiritu et al., 2021). Average outdoor temperature was $16^{o}$ C to $23^{o}$ C.

### 3.3.2 Treatments and experiment design

Treatments comprised a factorial arrangement of four moisture regimes and five green gram varieties. Soil moisture regimes were 100%, 80%, 60%, and 40% field capacities while the varieties included two old releases N26 and KS20, and three new counterparts Karembo, Biashara and Ndengu Tosha. Experiments were carried out in a greenhouse but due to considerable tree shade effect, treatments were set in a randomized complete block design with three replications.

### 3.3.3 Preparation of growing media and calibration of soil field capacity

Undisturbed soil was collected from a site near the greenhouse. Two parts of the soil were mixed with one part of sand and one part of cow manure in the ratio 2:1:1 before filling in pots. A total of three hundred pots were filled with 10kg soil mixture, thereafter, sub-divided into three groups each consisting of one hundred pots per replication.

A sample collected from the prepared media was taken to the laboratory for field capacity determination. Three rings were filled with the sample soil before saturating them completely with water. The rings were labelled well to enable easy tracking of the results from each ring. Using a weighing balance, the wet weight from the three rings was recorded, thereafter the rings were placed on a pressure plate at 0.3kPa to remove the soil moisture without disturbing the soil structure. The rings were removed from the pressure plate after 24 hours then weighed individually. Thereafter, the rings were placed inside an oven for 24 hours after which they were removed and dry weight recorded. Soil moisture was computed gravimetrically as the difference between the wet weight and dry mass. Gravimetric measurements were multiplied with soil bulk density to obtain volumetric moisture content, as presented in Equation 1.

$$\text{Moisture} = \frac{(\text{wet weight} - \text{dry weight})}{\text{dry weight}} \times \text{bulk density} \quad \text{............................................Equation 1}$$

The moisture results computed were equated to $100cm^3$ and the formula used to obtain the amount of moisture for each pot using the standard volume of each pot. This helped in getting the amount of water that was to be applied for the four different regimes. Soil water potential was monitored using a tensiometer (Soil moisture probe CAT. NO.2900F-Soilmoisture Equipment Corp. Santa

Barbara, California USA) positioned at 13 cm depth. The tensiometers were calibrated to measure availability of water in the pots. As soon as the water potential reached –8 kPa, plants were watered to 100%, 80%, 60% and 40% field capacity.

### 3.3.4 Crop husbandry

Three seeds were sown in each pot at a depth of 5 cm. The pots were watered to 100% FC until they were fully established. Respective moisture regimes were introduced at the third trifoliate stage. When the crops emerged, fungal diseases were regulated using a single dose of Rodazim® (benzimidazoles) applied at a rate of 30ml/30L for drenching into the soil and 10ml/10L for spraying on the leaves. Weeding was done whenever weeds emerged on the pots and walking paths.

### 3.3.5 Data collection

Three plants were randomly selected from five pots for each treatment and tagged. Repeat measurements included crop phenology, crop growth and root traits, and yield components. Crop phenology was scored regularly from germination through to maturity with emphasis on branching, flowering, podding and maturity. Number of days to each of these stages were scored when 50% of the plants per treatment pot reached the respective growth stage. However, physiological maturity was scored as time to 75% change in pod ripeness per treatment pot. As an indicator of physiological maturity, pods of variety KS20 and Karembo  became brown while those of N26, Biashara and Ndengu Tosha turned black.

Plant height (cm) was measured from the soil surface and the tip of the central shoot of mature plants. One plant per pot was randomly selected from each treatment, measured using a ruler at branching and flowering stage. Crops were also sampled for total number of nodules, active nodules, nodule weight, root length and angel at branching and flowering. At each sampling stage, a pot containing three plants was thoroughly applied with water and the pots gently destroyed. Roots were carefully washed with running water to remove soil. Total number of nodules was obtained by counting the number of nodules per plant.

Active number of nodules was determined by slicing the nodules intohalves and observing the pink pigmentation. Nodules with pink pigment were recorded as active nodules. Nodule dry mass was determined after drying the nodules in an oven at 70$^{o}$C for 24 hours to aconstant weight which was determined by a digital weigh balance. Root length and root angle werealso measured from the sampled roots from which the nodules were extracted. Clear images of individual roots were captured using a camera, analyzed afterwards using image J software.

Leaf greenness was determined using a SPAD meter (Soil Plant Analysis Development SPAD- 502, Minolta Camera Co. Ltd…Japan) SP on the fully developed middle leaf of the trifoliate. Number of pods per plant were obtained by counting pods at maturity from three randomly selected plants. Number of seeds per pod were achieved by randomly selecting 5 pods per treatment, splitting the pods, then counting the number of seeds from each pod. Seed yield was obtained by threshing all the pods from every treatment, then weighed using a digital scale.

### 3.3.6 Data analysis

Data were subjected to analysis of variance (ANOVA) to assess the experimental sources of variation for all traits using GenStat 15th edition. A two-way ANOVA routine was used, with replicate (block) and variety as factors, while variables consisted of the collected measurements. Prior to analysis, data was tested for normality and conformed to requirements of ANOVA. Residuals were checked for normal distribution, and no transformations were required. Treatment means were compared and separated using Fisher's Least Significant Difference (LSD) at 5% probability test.

## 3.4 Results

### 3.4.1 Crop phenology

Table 3.1 presents phenological development of green gram. The five green gram varieties revealed significant differences ($P<0.05$) in developmental rate. Consistently, variety N26 matured 5 days late compared with the rest of the varieties. However, in a few occasions there were no differences between KS20 and N26. Crop developmental rates did not differ among the new varieties, including Biashara, Karembo and Ndengu-Tosha.

Pooled data across the five varieties did not show significant effects of moisture regime on green gram phenology (Table 3.1). Further, there were no significant interactions between variety and moisture regime for crop phenology.

Table 3.1. Mean number of days to 50% branching, flowering and physiological maturity of fivegreen gram varieties grown under different moisture regimes

| Treatment | Experiment cycle 1 | | | | Experiment cycle 2 | | | |
|---|---|---|---|---|---|---|---|---|
| | Branch | Flower | Podding | Mature | Branch | Flower | Podding | Mature |
| Variety | | | | | | | | |
| N26 | 34a | 46a | 54a | 68a | 36a | 46a | 54a | 70a |
| KS20 | 33a | 43b | 49b | 63b | 33b | 44a | 49b | 65b |
| Biashara | 31b | 41bc | 49b | 63b | 32b | 41b | 49b | 65b |
| Karembo | 31b | 39c | 48b | 62b | 32b | 39b | 48b | 64b |
| Ndengu Tosha | 31b | 39c | 49b | 63b | 32b | 39b | 49b | 65b |
| P value | 0.001 | <0.001 | <0.001 | <0.001 | <0.001 | <0.001 | <0.001 | <0.001 |
| LSD | 1.6 | 2.9 | 2.0 | 2.0 | 1.2 | 3.0 | 2.0 | 2.0 |
| CV% | 6.0 | 8.4 | 4.8 | 3.7 | 4.4 | 8.5 | 4.9 | 3.6 |
| Moisture regime (field capacity) | | | | | | | | |
| 40% FC | 32a | 41a | 50a | 64a | 33a | 41a | 50a | 66a |
| 60% FC | 32a | 42a | 50a | 64a | 33a | 42a | 50a | 66a |
| 80% FC | 33a | 41a | 49a | 63a | 34a | 41a | 49a | 65a |
| 100% FC | 32a | 42a | 50a | 64a | 33a | 43a | 50a | 66a |
| P value | 0.624 | 0.470 | 0.639 | 0.541 | 0.515 | 0.515 | 0.572 | 0.541 |
| LSD | 1.4 | 2.6 | 1.8 | 1.8 | 1.1 | 2.6 | 1.8 | 1.8 |
| CV% | 2.1 | 2.0 | 0.6 | 0.5 | 1.9 | 2.0 | 0.7 | 0.5 |
| Interactions (P values) | | | | | | | | |
| Variety × FC | 0.832 | 0.85 | 0.974 | 0.934 | 0.83 | 0.914 | 0.957 | 0.934 |

Means followed by the same letter within a column are not significantly different at P<0.05

### 3.4.2 Plant height

Varietal differences in plant height, and the effect of moisture regime and its interaction with variety are presented in Table 3.2. Significant differences (P<0.05) in plant height among five green gram varieties was recorded. Variety N26 was 5 cm taller than the average height of the restof varieties at branching and flowering stages, KS20 was the second tallest while Biashara was theshortest.

Additionally, significant difference (P<0.05) between the four moisture regimes was also recorded in the first experiment whereby, plants under 40% field capacity were 4 cm shorter than the average height of the other three moisture levels. Crops grown at 100% field capacity were the tallest, followed by 80% and 60% field capacity respectively.

Table 3.2. Mean plant height (cm) at 50% branching and flowering of five green gram varietiesgrown under different moisture regimes

| Treatment | Experiment cycle 1 | | Experiment cycle 2 | |
|---|---|---|---|---|
| | Branching | Flowering | Branching | Flowering |
| Variety | | | | |
| N26 | 37.7a | 40.5a | 34.3a | 38.5a |
| KS20 | 33.6b | 36.7b | 32.9a | 33.6b |
| Biashara | 30.3c | 33.1d | 30.1b | 34.2b |
| Karembo | 31.8bc | 34.8c | 31.9ab | 34.1b |
| Ndengu Tosha | 33.2b | 36.4b | 33.2a | 34.1b |
| P value | <0.001 | <0.001 | 0.017 | <0.001 |
| LSD | 2.2 | 1.1 | 2.5 | 2.1 |
| CV% | 8 | 7.1 | 9.2 | 7.2 |
| Moisture regime (field capacity) | | | | |
| 40% FC | 30.9b | 34.0b | 31.4a | 35.1a |
| 60% FC | 34.4a | 37.3a | 32.1a | 34.4a |
| 80% FC | 33.1a | 36.2a | 32.5a | 35.0a |
| 100% FC | 35.0a | 37.7a | 34.0a | 35.0a |
| P value | <0.001 | 0.002 | 0.120 | 0.885 |
| LSD | 2.0 | 1.9 | 2.2 | 1.9 |
| CV% | 4.3 | 3.9 | 4.4 | 2.3 |
| Interactions (P values) | | | | |
| Variety × FC | 0.53 | 0.49 | 0.795 | 0.918 |

Means followed by the same letter within a column are not significantly different at P<0.05

### 3.4.3 Nodulation

Table 3.3 and 3.4 display varietal differences in nodulation and the effect of varying moisture regime and its interaction with variety. In both cycles, N26 had significantly higher number of nodules and the lowest numbers were recorded in Biashara, KS20, Karembo and Ndengu Tosha.

Furthermore, there was a significant difference observed on the active nodules, with KS20 having the highest number of active nodules. Data of the four moisture regimes displayed significant differences (P<0.05) in total number of nodules per plant, number of active nodules and nodule dry weight. Moisture levels of 60% and 80% showed the highest total number of nodules and active nodules compared to 40% and 100%.

Table 3.3. Number of nodules per plant, active nodules per plant and nodule dry mass per plant at50% branching of five green gram varieties grown under different moisture regimes

| Treatment | Experiment cycle 1 | | | Experiment cycle 2 | | |
|---|---|---|---|---|---|---|
| | Total | Active | Dry mass (g) | Total | Active | Dry mass (g) |
| Variety | | | | | | |
| N26 | 15.7a | 7.8ab | 0.550a | 13.3a | 6.8a | 0.816a |
| KS20 | 14.3a | 9.2a | 0.536a | 12.0a | 5.7a | 0.780a |
| Biashara | 11.0b | 6.3b | 0.578a | 8.8b | 4.0b | 0.767a |
| Karembo | 13.0ab | 6.8b | 0.558a | 10.9ab | 5.0ab | 0.772a |
| Ndengu Tosha | 14.1a | 8.1ab | 0.555a | 11.3ab | 5.4ab | 0.751a |
| P value | 0.027 | 0.026 | 0.389 | 0.025 | 0.012 | 0.603 |
| LSD | 2.8 | 1.8 | 0.040 | 2.7 | 1.5 | 0.080 |
| CV% | 5.1 | 5.7 | 9.3 | 28.8 | 33.5 | 12.9 |
| Moisture regime (field capacity) | | | | | | |
| 40% FC | 10.5b | 5.0b | 0.502c | 7.8c | 3.8b | 0.757ab |
| 60% FC | 15.7a | 8.6a | 0.547b | 13.4a | 6.3a | 0.827a |
| 80% FC | 15.7a | 9.1a | 0.580ab | 13.4a | 6.7a | 0.736b |
| 100% FC | 12.5b | 7.8a | 0.593a | 10.3b | 4.7b | 0.736b |
| P value | <0.001 | <0.001 | <0.001 | <0.001 | <0.001 | 0.089 |
| LSD | 2.5 | 1.6 | 0.040 | 2.4 | 1.3 | 0.070 |
| CV% | 25.1 | 29.1 | 6.9 | 6 | 7 | 2.3 |
| Interactions (P values) | | | | | | |
| Variety × FC | 0.745 | 0.949 | 0.006 | 0.279 | 0.079 | 0.878 |

Means followed by the same letter within a column are not significantly different at P<0.05

Table 3.4. Total number of nodules per plant, active nodules per plant, and nodule dry mass perplant of five green gram varieties grown under different moisture regimes

| Treatment | Experiment cycle 1 | | | Experiment cycle 2 | | |
|---|---|---|---|---|---|---|
| | Total | Active | Dry mass (g) | Total | Active | Dry mass (g) |
| Variety | | | | | | |
| N26 | 16.4a | 9.3a | 0.508a | 16.6a | 7.4a | 0.938a |
| KS20 | 15.2ab | 9.1a | 0.503a | 14.2a | 6.9a | 0.885a |
| Biashara | 12.3c | 7.2b | 0.494a | 11.8ab | 5.8a | 0.931a |
| Karembo | 14.3abc | 7.6b | 0.473a | 13.9a | 7.4a | 0.922a |
| Ndengu Tosha | 13.2bc | 8.5ab | 0.502a | 12.3ab | 6.3a | 0.970a |
| P value | 0.018 | 0.056 | 0.512 | 0.036 | 0.314 | 0.735 |
| LSD | 2.5 | 1.7 | 0.042 | 3.2 | 1.8 | 0.121 |
| CV% | 21.2 | 24.5 | 10.5 | 27.9 | 32.7 | 16.1 |
| Moisture regime (field capacity) | | | | | | |
| 40% FC | 11.2b | 7.0b | 0.463b | 11.2b | 5.2b | 0.979a |
| 60% FC | 16.6a | 9.5a | 0.507a | 15.9a | 7.9a | 0.902a |
| 80% FC | 16.0a | 8.9a | 0.491ab | 15.1ab | 7.9a | 0.939a |
| 100% FC | 13.3b | 8.0ab | 0.523a | 12.9b | 6.1b | 0.897a |
| P value | <0.001 | 0.012 | 0.021 | 0.008 | 0.003 | 0.425 |
| LSD | 2.2 | 1.5 | 0.042 | 2.8 | 1.6 | 0.111 |
| CV% | 6.6 | 14.2 | 0.9 | 7 | 4.5 | 2.5 |
| Interactions (P values) | | | | | | |
| Variety × FC | 0.82 | 0.234 | 0.696 | 0.227 | 0.439 | 0.238 |

Means followed by the same letter within a column are not significantly different at $P<0.05$

### 3.4.4 Root length and angle

Tables 3.5 and 3.6 show difference in root length and root angle between five varieties grow under varying moisture regime and its interaction. No significant differences $P>0.05$ in root lengthand angle between five green gram varieties grown under four moisture regimes at branching and flowering were noted.

Table 3.5 Root length (cm) at 50% branching and flowering of five green gram varieties grown under different moisture regimes

| Treatment | Experiment cycle one | | Experiment cycle two | |
|---|---|---|---|---|
| | Branching | Flowering | Branching | Flowering |
| Variety | | | | |
| N26 | 16.2a | 14.3a | 10.7a | 11.4a |
| KS20 | 13.9a | 13.4a | 11.0a | 11.6a |
| Biashara | 16.8a | 15.2a | 12.1a | 12.6a |
| Karembo | 15.1a | 14.3a | 12.6a | 13.5a |
| Ndengu Tosha | 15.9a | 14.8a | 12.4a | 12.8a |
| P value | 0.256 | 0.411 | 0.136 | 0.145 |
| LSD | 2.7 | 1.9 | 1.9 | 1.8 |
| CV% | 20.7 | 16.3 | 19.2 | 18 |
| Moisture regime (field capacity) | | | | |
| 40% FC | 16.6a | 14.2a | 12.9a | 13.8a |
| 60% FC | 16.0a | 14.6a | 11.5a | 12.2a |
| 80% FC | 14.8a | 14.4a | 11.2a | 11.9a |
| 100% FC | 15.0a | 14.3a | 11.3a | 11.9a |
| P value | 0.400 | 0.953 | 0.176 | 0.055 |
| LSD | 2.4 | 1.7 | 1.7 | 1.6 |
| CV% | 11.4 | 8.1 | 2.5 | 2.6 |
| Interactions (P values) | | | | |
| Variety × FC | 0.772 | 0.416 | 0.748 | 0.82 |

Means followed by the same letter within a column are not significantly different at $P<0.05$

Table 3.6. Root angle ($^o$) for the five varieties under different moisture regimes at 50% branchingand 50% flowering.

| Treatment | Experiment cycle 1 | | Experiment cycle 2 | |
|---|---|---|---|---|
| | Branch | Flower | Branch | Flower |
| Variety | | | | |
| N26 | 51.82a | 49.63a | 37.83a | 40.67a |
| KS20 | 45.56a | 44.56a | 41.58a | 45.63a |
| Biashara | 39.92a | 39.09a | 42.18a | 40.28a |
| Karembo | 47.40a | 45.04a | 37.04a | 41.33a |
| Ndengu Tosha | 49.76a | 48.52a | 43.19a | 41.21a |
| P value | 0.219 | 0.207 | 0.089 | 0.329 |
| LSD | 10.63 | 9.50 | 5.32 | 6.87 |
| CV% | 27.4 | 25.3 | 16 | 16.4 |
| Moisture regime (field capacity) | | | | |
| 40% FC | 44.49a | 42.21a | 42.53a | 43.46a |
| 60% FC | 47.76a | 46.33a | 41.09a | 41.26a |
| 80% FC | 45.41a | 44.19a | 38.58a | 39.64a |
| 100% FC | 49.90a | 48.74a | 39.25a | 42.94a |
| P value | 0.660 | 0.453 | 0.336 | 0.425 |
| LSD | 9.51 | 8.49 | 4.76 | 5.08 |
| CV% | 3.9 | 4.5 | 3 | 3.7 |
| Interactions (P values) | | | | |
| Variety × FC | 0.93 | 0.978 | 0.905 | 0.767 |

Means followed by the same letter within a column are not significantly different at P<0.05

### 3.4.5 Leaf greenness

Varietal difference in leaf greenness and the effect of varying moisture regime and its interaction with variety is presented in Table 3.7. Significant differences (P<0.05) on leaf greenness (SPAD) units were recorded between green gram varieties and moisture regimes at branching and flowering stage. Variety N26 had four SPAD units more than the average recorded by the other four varieties namely KS20, Biashara, Karembo and Ndengu Tosha. Crops grown under 80% FC and 100% FC had 7.0 SPAD units more than the counterparts grown under 40% and 60% FC, which on average recorded 35.0 and 39.0 SPAD units, respectively.

Table 3.7. Leaf greenness (SPAD units) at 50% branching and flowering of five green gramvarieties grown under different moisture regimes

| Treatment | Experiment cycle 1 | | Experiment cycle 2 | |
|---|---|---|---|---|
| | Branching | Flowering | Branching | Flowering |
| Variety | | | | |
| N26 | 44.2a | 43.4a | 43.1a | 40.6a |
| KS20 | 41.2b | 39.6b | 40.1b | 38.0b |
| Biashara | 40.6b | 39.0b | 40.2b | 38.5b |
| Karembo | 41.2b | 38.8b | 40.3b | 37.6b |
| Ndengu Tosha | 41.3b | 39.3b | 41.1b | 38.7ab |
| P value | 0.008 | 0.001 | 0.006 | 0.038 |
| LSD | 2.0 | 2.4 | 2.4 | 2.0 |
| CV% | 5.8 | 7.1 | 5.2 | 6.2 |
| Moisture regime (field capacity) | | | | |
| 40% FC | 36.1b | 34.8b | 35.6b | 33.4c |
| 60% FC | 43.0a | 40.7ab | 42.3a | 39.8b |
| 80% FC | 43.0a | 41.4a | 41.5ab | 39.4b |
| 100% FC | 44.7a | 43.2a | 43.2a | 42.2a |
| P value | <0.001 | <0.001 | <0.001 | <0.001 |
| LSD | 1.8 | 2.1 | 1.6 | 1.8 |
| CV% | 2.3 | 1.9 | 0.5 | 1.8 |
| Interactions (P values) | | | | |
| Variety× FC | 0.054 | 0.334 | 0.093 | 0.319 |

Means followed by the same letter within a column are not significantly different at P<0.05

### 3.4.6 Yield components

Table 3.8 presents varietal differences in yield components, and the effect of varying moisture regime and its interaction with varieties. Significant differences (P<0.05) in the yield components among five green gram varieties were noted. Variety Ndengu Tosha had a greater number of pods per plant, N26 had the longest pod length and more seeds in the pods than the other varieties. Karembo had the shortest pod length while Biashara had lower number of seeds per pod. Significant differences (P< 0.05) between the moisture regimes were observed in the number of pods per plant. Plants under 100% FC had a higher number of pods than their counterparts.

Table 3.8. Number of pods per plant, pod length, number of seeds per pod and seed yield offive green gram varieties grown under four moisture regimes

| Treatment | Experiment cycle 1 | | | | Experiment cycle 2 | | | |
|---|---|---|---|---|---|---|---|---|
| | Pods | Length (cm) | Seeds/pod | Yield (g/plant) | Pods | Length (cm) | Seeds/pod | Yield (g/plant) |
| Variety | | | | | | | | |
| N26 | 6.4a | 7.5a | 9.6a | 26.2a | 6.2a | 7.5a | 9.6a | 28.1a |
| KS20 | 4.9b | 6.6b | 8.4b | 21.4a | 5.3b | 7.3a | 8.4b | 22.5a |
| Biashara | 6.5a | 6.4b | 6.3d | 19.2a | 5.4ab | 6.7b | 6.3d | 20.6a |
| Karembo | 5.4ab | 6.1b | 7.0c | 24.3a | 6.0a | 6.6b | 7.0c | 26.4a |
| Ndengu Tosha | 7.3a | 6.3b | 7.0c | 24.5a | 6.7a | 6.8b | 7.0c | 27.2a |
| P value | 0.004 | <0.001 | <0.001 | 0.303 | 0.045 | <0.001 | <0.001 | 0.246 |
| LSD | 1.3 | 0.6 | 0.7 | 7.1 | 1.0 | 0.3 | 0.7 | 7.8 |
| CV% | 25.3 | 10.9 | 1.3 | 37.1 | 21.2 | 4.9 | 10.3 | 37.9 |
| Moisture regime (field capacity) | | | | | | | | |
| 40% FC | 5.7b | 6.4b | 7.4a | 14.3b | 4.8b | 6.8a | 7.4a | 15.9b |
| 60% FC | 5.7b | 6.1b | 7.7a | 26.0a | 6.1a | 6.9a | 7.7a | 27.2a |
| 80% FC | 5.7b | 6.6b | 7.9a | 28.1a | 6.6a | 7.2a | 7.9a | 30.3a |
| 100% FC | 7.2a | 7.5a | 7.7a | 24.0a | 6.2a | 7.0a | 7.7a | 26.5a |
| P value | 0.026 | 0.524 | 0.486 | <0.001 | 0.002 | 0.057 | 0.486 | 0.001 |
| LSD | 1.1 | 0.5 | 0.6 | 6.3 | 0.9 | 0.3 | 0.6 | 7.0 |
| CV% | 10.8 | 1.3 | 10.3 | 21 | 2 | 1.1 | 1.3 | 22.7 |
| Interactions (P values) | | | | | | | | |
| Variety× FC | 0.038 | 0.955 | 0.675 | 0.886 | 0.151 | 0.955 | 0.962 | 0.846 |

Means followed by the same letter within a column are not significantly different at P<0.05

## 3.5 Discussion

### 3.5.1 Effect of variety and moisture regime on crop growth and root traits

While the five green gram varieties matured at different times, crop phenology was neither affected by moisture regime nor the interaction between variety and moisture regime. Variety N26matured late compared with the rest of the varieties. Earliness is one of the key traits targeted for adaptation of green gram to moisture stress (Mulwa et al., 2023). The observed earliness in the new varieties including Biashara, Karembo and Ndengu Tosha could be attributed to advanced breeding efforts to adapt green gram to frequent moisture deficits (Mulwa et al., 2023). In the advent of climate change, which has occasioned increase in temperature and heat stress, the new varieties would therefore out-perform their older late maturity counterparts.

Crop growth traits among the five green gram varieties grown under four moisture regimes varied significantly. This observation agrees with (Patra et al., 2020) that ability to survive drought differs among the varieties. Variety N26 was the tallest followed by KS20 and Biashara was the shortest of all the varieties. Crops grown under 40% moisture level were shorter than those under 60%, 80% and 100% water regimes. Drought conditions led to the observation of shorter plants compared to those receiving sufficient water, attributed to a decrease in cell enlargement (Kapoor et al., 2020). Moisture stress is a limiting factor in crop growth and establishment. It hinders crops from attaining maximum growth potential expected in their genotypes (Chowdhury et al., 2021).

Significant differences were observed in crop nodulation among the five green gram varieties grown under four moisture regimes. Variety N26 had the highest number of nodules and active nodules than the other varieties. Rhizobia species responsible in nodulation of pulses is host specific and can vary among the genotypes of same species (Goyal et al., 2021). This variation in nodulation could be used in breeding programs to select and enhance biological nitrogen fixation in green grams thus improved soil fertility. Additionally, plants under 40% had a lower total number of nodules as well as active nodule compared to 60%, 80% and 100% field capacities. This is as a result of drought which causes reduction in root development and physiological changes. Drought stress also suppresses the growth of nodules, resulting in a decrease in nodulation of legumes (Goyal et al.,2021).

Leaf greenness varied significantly among the green gram varieties with N26 having more SPAD units compared to the other varieties. High SPAD units in N26 than the other varieties across all the moisture regimes resulted to higher chlorophyll content thus increase in photosynthesis resulting to more yield. On the other hand, 40% moisture regime showed lower SPAD units. Drought stress result in low chlorophyll content and minimum light harvesting which causes reduced photosynthesis (Zhuang et al., 202).

Root length and root angle did not show any significant differences among the five green gram varieties grown under four moisture regimes, 40%, 60%, 80% and 100%. There is limited knowledge on the green gram root traits and how it can be used in breeding toward drought tolerance. However, in crops such as common bean, soybean, chickpea and cowpea, root traits such as root length, root angle and root mass are promising for drought avoidance trait and could be used for breeding drought resistant legume genotypes (Khatun et al., 2021). Nevertheless, some present studies have reported that selection for yield under terminal drought conditions is not essentially dependent on root systems, but rather on several other critical traits including early flowering, podding and maturity provide an escape mechanism, and may be used for breeding drought tolerant varieties (Khatun et al., 2021).

### 3.5.2 Effect of variety and moisture stress on yield components

Variety N26 took more days to mature although it was a high yielding. Crops grown under 100% field capacity had a greater number of pods per plant, seeds per pods and seed yield followed by 80% and 60% field capacity while those at 40% field capacity had the lowest. This supports a report by (Karimi et al., 2019) that adaptability and productivity of green gram is adversely affected by several abiotic stresses including drought, heat, and waterlogging which affect crop growth and development by altering physiological processes and the crop-moisture relationship. Water stress has an impact on physiological processes as well as factors that determine yield (Khatun et al., 2021). It results to decrease in crop yields through reduction of photosynthetic active radiation interception, radiation efficiency and harvest index (Saha et al., 2022).

### 3.5.3 Interactive effects of variety and moisture regime on crop growth and yield

Crop growth and productivity are adversely affected by water stress. Therefore, development of crops with increased ability to survive during extreme moisture stress is a major focus in crop breeding. However, the studied green gram varieties did not show any interaction between variety and moisture regime in phenology, plant height, nodulation, leaf greenness and yield components. This could potentially imply that breeding may not have selected specific traits to for adaptation to moisture deficit.

## 3.6 Conclusion

In this study, it is evident that moisture stress impacts crop growth and yield of green grams. Selected varieties adapted differently to varying moisture regimes. Crop phenology, nodulation, pods per plant and yield varied among the varieties. Although N26 matured late, it expressed superior crop growth traits with high yield compared to Biashara, Karembo and Ndengu Tosha, early maturing varieties which were recently released. Therefore, there is need to evaluate the response of released green gram varieties to varying moisture regimes. Varieties under 80% and 100% FC showed good crop performance with high yield while those at 40% FC recorded lower yield. This could be attributed to severe moisture stress. Nonetheless, interactions between varying moisture regime and variety were not observed. This emphasizes that breeding advances to adapt green gram varieties to moisture stress while improving yields is key.

# CHAPTER 4: EVALUATION OF ADAPTATION OF SELECTED GREEN GRAM VARIETIES TO NO-TILLAGE AND RESIDUE RETENTION SYSTEMS

## 4.1 Abstract

Green gram (*Vigna radiata* L.) is an important legume that is well adapted to dryland areas of Kenya where it is grown for food and income generation. Although breeding has improved drought tolerance in green gram, yield gaps remain large due to increasingly low and poorly distributed rainfall. While no-tillage and residue retention systems conserve soil moisture, there exists no evidence on the breeding of green gram for adaptation to these systems in Kenya. However, newer varieties could have inadvertently acquired traits for adaptation to no-till during the later years of selection compared with their older counterparts. To identify the traits for adaptation of green gram to no-tillage systems, a selection of old and new varieties was evaluated under no-till with residue retention, and conventional tillage with bare ground. Old varieties comprised N26 and KS20, both released in 1990s while new counterparts were Biashara, Karembo and Ndengu Tosha, released in 2017. Experiments were carried out on-station at KALRO Katumani and at a farmer's field in Kikesa during 2020 short rains and 2021 long rains seasons. The trials were laid out in a randomized complete block design with split-plot arrangement, whereby tillage formed the main plots while varieties were assigned to subplots. Crop growth traits and yield measurements were subjected to analysis of variance using GenStat software at 5% probability. In both Katumani and Kikesa, green gram varieties varied significantly in phenology. Variety N26 took 105 days to reach maturity while the other four varieties matured between 75-90 days. Differences among the varieties were measured in number of nodules with N26 and KS20 recording higher number of nodules per plant. Variety N26 was the tallest variety by 9 cm while Biashara was the shortest. Additionally, N26 had the highest number of pods per plant, pod length, seeds per pods and high yield of 0.9 t/ha compared to the other varieties whose average yield was 0.6 t/ha. However, the study did not show significant effects of tillage system, as well asits interaction with variety. Although the selected varieties exhibited notable variations in growth and yield, breeding efforts have yet to prioritize specific traits for adaptation to tillage systems in green gram.

Key words: conventional tillage, no-till, residue retention, conservation

## 4.2 Introduction

Legumes are increasingly becoming a source of food globally due to their nutrient dense grains (Semba et al., 2021). Green gram is grown for its nutritional grain and economic value (Kamiti et al., 2019). Green gram adapts to a wide range of environments, requires minimal nutrient inputs, and improves soil fertility through biological nitrogen fixation (Kebede, 2021). Production of green gram is mainly situated in Asia with India producing the largest quantities of more than 50% worldwide. Green gram has demonstrated its ability to thrive in drier areas of Kenya due to its early maturity (Karimi et al., 2019). South eastern regions of Kenya, namely Machakos, Makueni and Kitui are known to be leading in green gram production in Kenya. However, these regions have not been able to produce enough green gram to meet growing demand in the country.

Recently, estimated green gram yield obtained by farmers was approximately 0.5 t/ha compared to a yield potential of 4.5 t/ha (Mugure et al., 2023). Yield potential refers to yield of a crop when cultivated in its adapted environment with adequate supply of water and nutrients, through sufficient elimination of yield-limiting factors such as pests, diseases and weeds (Mugo et al., 2023)**.** This large yield gap could be attributed to drought, pests and diseases, as well as poor agronomicpractices. Efforts by plant breeders to adapt green gram varieties to drought have been achieved through development of varieties that mature early (Mulwa et al., 2023). However, inadequate soil moisture remains a huge constraint to productivity of green gram in the semi-arid areas of Kenya (Mugo et al., 2023).

The escalating degradation of agricultural land and the impacts of climate change necessitate a shift in agronomic practices. This includes adopting moisture conservation strategies like minimum soil disturbance, zero tillage, and retaining crop residues (Mugo et al., 2023). The concept of conservation agriculture, has advanced in recent years with legumes considered an important component in these systems (Karimi et al., 2019). To meet increased green gram demand with inadequate water and land in semi-arid regions, farming systems with high water efficiency are required in the future.

Improvements in soil moisture management through no tillage system may prove to be a key up-grade in smallholder farming systems in dry sub- humid and semi-arid areas. Therefore, this study sought to examine the response of selected green gram varieties to no tillage and residue retention system. This study hypothesized that breeding in green gram has not selected for adaptation to no till and residue retention.

## 4.3 Materials and methods

### 4.3.1 Experiment sites

Field experiments were carried out at the Kenya Agricultural and Livestock Research Organization (KALRO) station in Katumani, and in a farmer's field in Kikesa, both in MachakosCounty. It involved two seasons in both sites during 2020 short rains and 2021 long rains seasons. KALRO Katumani is located 1°34′58″S, 37°14′43″E and 1600 m elevation. The mean maximum and minimum temperature in Katumani are 25°C and 14°C, respectively. The site's soils consist of well-drained, dark red clay with a pH of 7.0 (Mbayaki and Kinama, 2022)

Farmer's field in Kikesa is located 1°16′26″S, 36°44′17″E and 1324 m above sea level. Kikesa is hotter than Katumani with mean maximum temperature of 35°C and mean minimum temperature of 17°C. Soils of Kikesa are well drained red brown to clay soils with a pH of 6.5. Rainfall in both sites has a bimodal distribution pattern with a long rains season from March to June and a short season from October to December. Long term data for Katumani shows 382 mm during thelong rains season, and 274 in the short season.

### 4.3.2 Treatments and experiment design

Treatments entailed two tillage systems and five green gram varieties. Tillage systems were conventional tillage without residue retention and no-tillage with the application of 3 t/ha crop residue, largely maize stalks. Green gram varieties were two old releases of KS20 and N26, and three new counterparts, including Biashara, Karembo and Ndengu Tosha.

Treatments were laid out in a randomized complete block design with split-plot arrangement and replicated three times. Tillage systems assumed the main plots while varieties were assigned to sub-plots. Each plot measured size 4 m × 3 m, with 1m alleyway between plots and 2 m gap between the replications.

### 4.3.3 Experiment management

Conventional tillage plots were tilled before onset of rains with a disc plough and harrowed to fine tilth and crop residue removed. No-tillage plots remained un-ploughed and crop residues retained at the rate of 3 t/ha. In the first season, crop residues were exclusively sourced from maize but in the second season, previous green gram residues were added. In the no-till plots, shallow planting holes were opened using a sharp hoe to hold the seed, and weeds controlled by uprooting. Green gram varieties were sown at the onset of rains at a spacing of 50 cm between rows and 10 cm from plant to plant. After crop emergence, cutworms and bean fly were managedusing a single dose of Thunder® (imidacloprid) at 10mL/10L water. Ridomil® (mancozeb) was applied at a rate of 50g/20L water to control bacterial and fungal diseases. In conventionally tilled plots, weeds were removed by hand hoeing.

### 4.3.4 Data collection

Data comprised weather parameters, crop phenology and growth traits, and yield components. Weather data during the growing season was obtained from KALRO Katumani meteorological stations near the experiment sites, and included daily rainfall, daily maximum and minimum temperatures. Crop phenology was measured regularly with particular focus on the number of days to 50% branching, flowering, podding and maturity. This was realized by recording the number of days from time of sowing to when 50% of the plants per plot formed branches, flowers and pods respectively. Number of days to physiological maturity was obtained by recording days from sowing up until when seventy five percent of the pods in each plot were dry.

Crop growth traits were assessed from five randomly selected plants from each plot. Plant height was sampled at 50% branching and flowering, and measured from stem above soil surface of the plant to the tip of the central shoot.

Number of nodules was obtained from sampling five plants from each plot. The ground was flooded with adequate water to make it easy for uprooting the plants without damaging the roots and nodules. Thereafter, roots were cleaned with adequate water carefully and the count taken from each plant, number of nodules from each plant were summed and averaged.

Active nodules were separated by slicing the nodules into half using a razor blade then observing for the pink pigment. Active nodules contain a pink pigment while inactive nodule lack this color. The nodule weight was acquired by drying up the all nodules from sampled plants in an oven then weighing it using a weigh balance.

Number of branches per plant were categorized into primary and secondary branches, whereby five plants from each plot were sampled. Primary branches were classified as those originating from the trunk whereas secondary branches were side branches subsidiary to the parent branch. Leaf greeness was measured using a SPAD meter (Soil Plant Analysis Development SPAD-502, Minolta Camera co. Ltd…Japan). SPAD meter measures the transmission of red and infra-red radiation through the leaf while calculating the relative SPAD meter value which corresponds to the amount of chlorophyll in the leaf. The upper middle fully expanded leaf of trifoliate from ten plants randomly selected in each plot were measured and averaged using SPAD meter. At physiological maturity, five plants were randomly selected and pod length measured using a ruler.

Harvesting was done at different time intervals among the five green gram varieties. For instance, KS20 and Karembo, were harvested when the pods changed to brown while N26, Biashara and Ndengu Tosha were harvested when pods became black. Ten plants were randomlysampled per plot for the determination of number of pods per plant and seeds per pod. To determine the number of seeds per pod, ten pods from each plot were split open, followed by counting the number of seeds, summing them and then finding the average. Entire plots were harvested but with the exception of guard rows, and yield expressed in t/ha. Three samples were drawn from each plot for determination of 100 seed weight. Harvest index was determined as ratio between seed yield and total biomass.

### 4.3.5 Data analysis

Data on all parameters were subjected to the analysis of variance (ANOVA) to measure the sources of experimental variation using GenStat 15th Edition. Data was verified for regularity and fulfilled the requirements of ANOVA. Residuals were checked for normal dispersion and there were no modifications to be made. Treatment means were compared and separated using Fisher's protected least significant difference (LSD) at 5%probability level.

## 4.4 Results

### 4.4.1 Weather data and crop phenology

Figure 4.1 presents temperature and cumulative rainfall data during 2020 short rains and 2021 long rains. In 2020 growing season, Katumani received 260 mm and 165 mm in 2021 growing season while Kikesa recorded 160 mm in 2020 and 155 mm in 2021. The temperature range was between 10°C and 35°C in both sites.

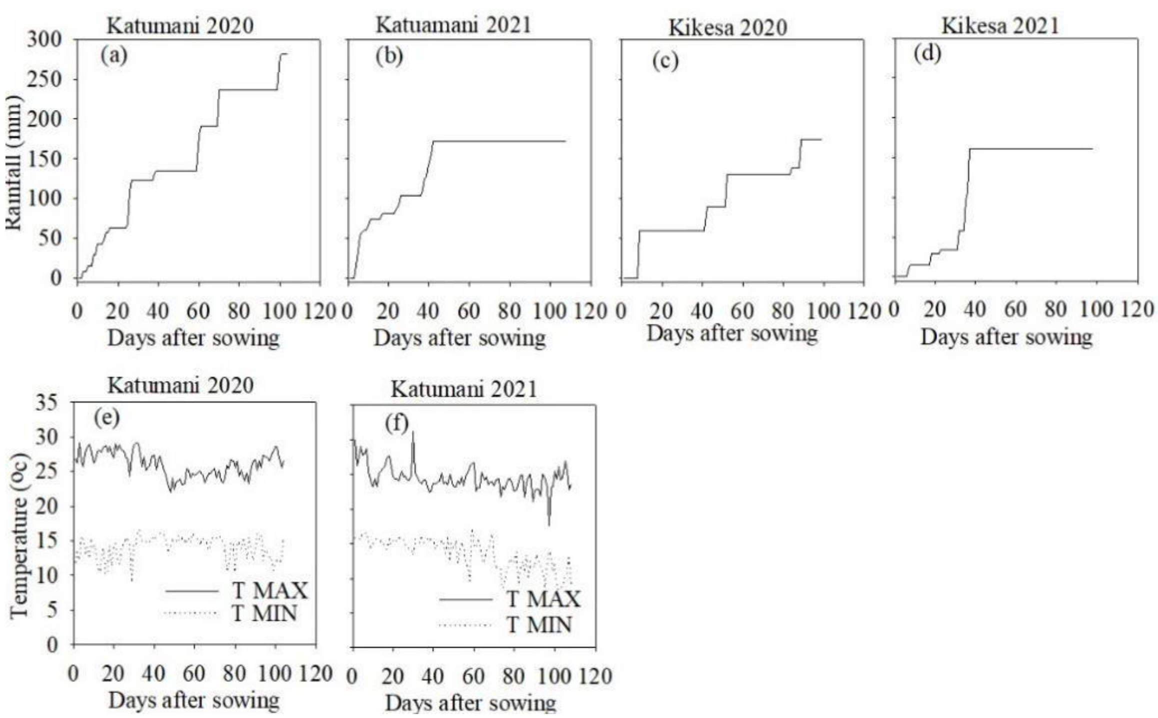


Figure 4.1. Cumulative rainfall during the short rain's seasons (a, c) and the long rains seasons (b,d), and daily minimum (T min) and maximum (T max) temperature (e, f) during the experimentaltime at Kenya Agricultural and Livestock Research Organization, Katumani research station and Kikesa farmer's field.

Phenological development of green gram varieties are presented in Table 4.1. Significant differences (P<0.05) in the developmental rate were recorded among the five green gram varieties. Notably, variety N26 exhibited a late maturation period, approximately 20 days later than the other varieties. The newly released varieties Karembo, Biashara, and Ndengu Tosha matured nearly simultaneously, with Ndengu Tosha taking an additional 4 days. Interestingly, data across all five varieties didn't indicate significant effects of tillage systems on green gram phenology. Varieties matured at similar times, irrespective of conventional or no tillage systems. Furthermore, no significant differences were observed among the five green gram varieties concerning their response to different tillage systems.

Table 4.1. Days to 50% branching (bran), flowering (flo) and maturity (mat)of five green gram varieties grown under twotillage systems in Katumani and Kikesa during 2020 short rains and 2021 long rains seasons

| Treatment | Katumani | | | | | | Kikesa | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 2020 short rains | | | 2021 long rains | | | 2020 short rains | | | 2021 long rains | | |
| | Bran | Flo | Mat | Bran | Flo | Mat | Bran | Flo | Mat | Bran | Flo | Mat |
| Variety | | | | | | | | | | | | |
| N26 | 54a | 59a | 104a | 54a | 59a | 108a | 53a | 55a | 99a | 50a | 55a | 98a |
| KS20 | 44b | 48c | 83d | 43bc | 47bc | 83c | 43b | 47b | 80b | 42b | 46bc | 79b |
| Biashara | 41c | 45d | 75e | 40c | 45c | 75d | 40c | 44c | 75c | 39b | 43c | 74c |
| Karembo | 45b | 49c | 90b | 44b | 49b | 90b | 44b | 48b | 82b | 44b | 47b | 81b |
| Tosha | 45b | 52b | 86c | 46b | 52b | 87b | 44b | 50b | 82b | 45b | 49b | 80b |
| P value | <0.001 | <0.001 | <0.001 | <0.001 | <0.001 | <0.001 | <0.001 | <0.001 | <0.001 | <0.001 | <0.001 | <0.001 |
| LSD | 1.6 | 2.7 | 1.1 | 2.4 | 4.0 | 3.3 | 1.1 | 3.8 | 3.8 | 2.8 | 3.6 | 4.0 |
| CV% | 0.8 | 1.7 | 0.4 | 1.1 | 1.2 | 1 | 0.5 | 1.1 | 4 | 3.1 | 0.5 | 1.3 |
| Tillage system | | | | | | | | | | | | |
| CT | 45a | 50a | 88a | 45a | 50a | 89a | 45a | 48a | 84a | 43a | 47a | 83a |
| NT | 46a | 51a | 88a | 46a | 51a | 90a | 45a | 49a | 84a | 45a | 48a | 82a |
| P value | 0.37 | 0.408 | 0.25 | 0.212 | 0.192 | 0.349 | 0.118 | 0.525 | 0.932 | 0.244 | 0.122 | 0.95 |
| LSD | 1.3 | 3.0 | 1.3 | 1.7 | 2.1 | 2.0 | 1.0 | 1.9 | 11.9 | 4.7 | 1.4 | 12.1 |
| CV% | 1.2 | 2.2 | 0.5 | 1.745 | 2 | 0.6 | 1.5 | 1.4 | 1.7 | 1.9 | 0.9 | 4.2 |
| Interactions (P values) | | | | | | | | | | | | |
| Variety×Tillage | 0.358 | 0.16 | 0.883 | 0.251 | 0.316 | 0.798 | 0.279 | 0.821 | 0.154 | 0.762 | 0.994 | 0.228 |

Means followed by the same letter within a column are not significantly different at P<0.05

### 4.4.2 Nodulation

Tables 4.2 and 4.3 shows differences in nodulation between green gram varieties and its interaction with tillage systems at branching and flowering respectively. The five varieties varied significantly ($P<0.05$) in total number of nodules per plant at branching and flowering. Consistently, N26 and KS20 showed the highest number of nodules while Biashara, Karembo and Ndengu Tosha did not show significant difference in the number of nodules per plants. Additionally, there were significant differences observed in the number of active nodules, with N26 and KS20 having the highest number. Data across the five varieties did not show significant effects of tillage systems on nodulation at branching. However, significant differences in the total number of nodules and active nodules were recorded during the first season at Katumani. Conventional tillage recorded more nodules than no-tillage system. Furthermore, there were no significant interactions between variety and tillage for total number of nodules, active nodules and nodule dry mass.

Table 4.2. Number of nodules per plant, number of active nodules per plant and nodule dry mass per plant at 50% branching of fivegreen varieties grown under different tillage systems in Katumani and Kikesa during 2020 short rains and 2021 long rains seasons

| Treatment | Katumani | | | | | | Kikesa | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 2020 short rains | | | 2021 long rains | | | 2020 short rains | | | 2021 long rains | | |
| | Total | Active | Mass(g) | Total | Active | Mass(g) | Total | Active | Mass(g) | Total | Active | Mass(g) |
| Variety | | | | | | | | | | | | |
| N26 | 18.4a | 11.5a | 0.578a | 22.8a | 16.3a | 1.052a | 12.6b | 8.2b | 0.500a | 17.5ab | 9.3a | 0.600a |
| KS20 | 21.0a | 12.5a | 0.582a | 26.8a | 14.8a | 1.108a | 20.1a | 13.3a | 0.510a | 19.0a | 9.5a | 0.540a |
| Biashara | 15.2ab | 8.2b | 0.560a | 7.5b | 5.5b | 0.770b | 9.4b | 6.7b | 0.500a | 10.2b | 6.2b | 0.600a |
| Karembo | 12.1b | 6.4b | 0.550a | 11.3b | 6.8b | 0.782b | 8.2b | 6.7b | 0.490a | 7.8b | 4.8b | 0.800a |
| Tosha | 15.3ab | 9.0ab | 0.533a | 9.2b | 5.5b | 0.723b | 10.7b | 7.4b | 0.490a | 12.8b | 7.0ab | 0.620a |
| P value | <0.001 | 0.004 | 0.542 | <0.001 | 0.003 | 0.038 | 0.001 | 0.002 | 0.306 | 0.002 | 0.007 | 0.27 |
| LSD | 3.6 | 3.0 | 0.070 | 7.7 | 6.3 | 0.310 | 5.0 | 3.2 | 0.022 | 5.5 | 2.7 | 0.240 |
| CV% | 3.8 | 9 | 4 | 24.3 | 19.8 | 9.7 | 8.2 | 6.5 | 1.2 | 14.6 | 6.7 | 10.1 |
| Tillage system | | | | | | | | | | | | |
| CT | 17.2a | 10.3a | 0.565a | 13.9a | 8.0a | 0.908a | 12.1a | 8.32a | 0.50a | 12.9a | 6.9a | 0.62a |
| NT | 15.6a | 8.7a | 0.556a | 17.1a | 11.6a | 0.866a | 12.3a | 6.64a | 0.50a | 14.1a | 7.9a | 0.64a |
| P value | 0.085 | 0.143 | 0.658 | 0.408 | 0.151 | 0.357 | 0.896 | 0.543 | 0.4 | 0.532 | 0.13 | 0.83 |
| LSD | 2.2 | 3.0 | 0.080 | 13.3 | 6.8 | 0.150 | 3.5 | 1.9 | 0.020 | 6.9 | 1.7 | 0.225 |
| CV% | 14.6 | 17.5 | 5.3 | 5.8 | 13.3 | 4.9 | 15.1 | 20.4 | 2.1 | 5.6 | 4.1 | 15.6 |
| Interactions (P values) | | | | | | | | | | | | |
| Variety×Tillage | 0.334 | 0.599 | 0.11 | 0.088 | 0.183 | 0.612 | 0.628 | 0.7 | 0.395 | 0.985 | 0.994 | 0.86 |

Means followed by the same letter within a column are not significantly different at P<0.05

Table 4.3. Total number of nodules per plant, active nodules per plant, and nodule dry mass per plant at 50% flowering of five green varieties grown under different tillage system in Katumani and Kikesa during 2020 shortrains and 2021 long rains seasons

| Treatment | Katumani | | | | | | Kikesa | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 2020 short rains | | | 2021 long rains | | | 2020 short rains | | | 2021 long rains | | |
| | Total | Active | Mass (g) | Total | Active | Mass (g) | Total | Active | Mass (g) | Total | Active | Mass (g) |
| Variety | | | | | | | | | | | | |
| N26 | 32.2a | 17.8a | 1.193a | 35.2a | 21.7a | 1.448a | 23.5a | 14.8b | 0.715b | 29.3b | 17.2b | 0.975b |
| KS20 | 29.0a | 16.0a | 1.022b | 34.3a | 22.7a | 1.483a | 29.7a | 19.3a | 0.702b | 36.5a | 20.7a | 0.967b |
| Biashara | 20.2b | 11.8b | 0.807c | 19.0b | 13.2b | 1.045b | 22.5ab | 11.8b | 0.727b | 27.7b | 16.2ab | 0.987b |
| Karembo | 17.8b | 10.0b | 0.787c | 22.7b | 14.7b | 0.970b | 19.3b | 10.5b | 0.638b | 25.3b | 15.5b | 0.888b |
| Tosha | 19.5b | 10.2b | 0.780c | 18.2b | 12.0b | 0.900b | 25.7a | 12.2b | 1.300a | 30.3b | 18.0b | 1.278a |
| P value | <0.001 | <0.001 | <0.001 | 0.001 | 0.005 | <0.001 | 0.048 | 0.001 | 0.054 | 0.023 | 0.024 | 0.056 |
| LSD | 3.69 | 2.88 | 0.14 | 9.01 | 6.24 | 0.25 | 6.59 | 3.54 | 0.27 | 6.4 | 3.1 | 0.26 |
| CV% | 6.5 | 14.2 | 6.9 | 30.4 | 29.2 | 18.5 | 3.2 | 9.6 | 13.6 | 2.4 | 10 | 10.2 |
| Tillage system | | | | | | | | | | | | |
| CT | 26.7a | 14.5a | 0.998a | 29.3a | 18.9a | 1.208a | 25.0a | 14.1a | 0.760a | 30.7a | 17.3a | 1.019a |
| NT | 20.7b | 11.9b | 0.837a | 22.4a | 14.7a | 1.131a | 23.3a | 13.4a | 0.765a | 29.0a | 17.3a | 1.019a |
| P value | 0.007 | 0.025 | 0.091 | 0.393 | 0.405 | 0.705 | 0.112 | 0.598 | 0.961 | 0.107 | 0.774 | 0.994 |
| LSD | 2.2 | 1.8 | 0.220 | 27.6 | 17.2 | 0.760 | 2.7 | 4.6 | 0.370 | 2.5 | 6.1 | 0.370 |
| CV% | 2.6 | 3.9 | 4.7 | 1.1 | 2.5 | 3.8 | 18.9 | 18.9 | 8 | 15.8 | 22 | 5.1 |
| Interactions (P values) | | | | | | | | | | | | |
| Variety×Tillage | 0.583 | 0.524 | 0.652 | 0.711 | 0.621 | 0.734 | 0.052 | 0.214 | 0.669 | 0.077 | 0.016 | 0.722 |

Means followed by the same letter within a column are not significantly different at P<0.05

### 4.4.3 Number of primary and secondary branches

Table 4.4 displays the number of primary and secondary branches of green gram varieties and its interaction with tillage systems. Varieties showed significant differences in both primary and secondary branches (P<0.05) in the first season. Variety N26 had more primary and secondary branches compared to the other four varieties which did not show any significance. No significant differences were observed between the varieties grown under the two tillage systems as well as the interaction between the five varieties and the tillage systems.

Table 4.4. Total number of primary (pri) and secondary (sec) branches per plant of the five greengram varieties grown under two tillage systems in Katumani and Kikesa during 2020 short rains and 2021 long rains seasons

| Treatment | Katumani | | | | Kikesa | | | |
|---|---|---|---|---|---|---|---|---|
| | 2020 short rains | | 2021 long rains | | 2020 short rains | | 2021 long rains | |
| | Pri | Sec | Pri | Sec | Pri | Sec | Pri | Sec |
| Variety | | | | | | | | |
| N26 | 3.38a | 2.21a | 3.39a | 1.94a | 3.21a | 2.13ab | 3.21a | 2.00a |
| KS20 | 2.71b | 1.79b | 2.78a | 1.56a | 2.63b | 1.75c | 2.63b | 1.67a |
| Biashara | 2.92b | 1.96ab | 3.00a | 2.11a | 3.00ab | 1.83bc | 3.00ab | 1.88a |
| Karembo | 2.88b | 1.88b | 2.94a | 2.00a | 3.08a | 2.08ab | 3.08a | 2.04a |
| Tosha | 2.88b | 2.13ab | 3.00a | 2.22a | 3.20a | 2.17a | 3.21a | 2.04a |
| P value | <0.001 | 0.038 | 0.092 | 0.133 | 0.045 | 0.035 | 0.045 | 0.055 |
| LSD | 0.27 | 0.29 | 0.43 | 0.53 | 0.41 | 0.31 | 0.4 | 0.38 |
| CV% | 5.3 | 7.2 | 6.3 | 5.9 | 8.4 | 10.7 | 8.4 | 15.7 |
| Tillage system | | | | | | | | |
| CT | 2.82a | 1.85a | 2.98a | 2.07a | 3.05a | 1.98a | 3.05a | 1.98a |
| NT | 3.08a | 2.13a | 3.07a | 1.87a | 3.00a | 2.00a | 3.00a | 1.95a |
| P value | 0.177 | 0.136 | 0.604 | 0.122 | 0.833 | 0.932 | 0.833 | 0.885 |
| LSD | 0.56 | 0.5 | 0.63 | 0.33 | 0.9 | 0.75 | 0.9 | 0.69 |
| CV% | 5.3 | 4 | 5.9 | 4.8 | 6 | 0.7 | 6 | 15.7 |
| Interactions (P values) | | | | | | | | |
| Variety×Tillage | 0.069 | 0.313 | 0.605 | 0.861 | 0.972 | 0.713 | 0.973 | 0.833 |

Means followed by the same letter within a column are not significantly different at P<0.05

### 4.4.4 Leaf greenness

Varietal difference in leaf greenness and its interaction with tillage systems is shown in Table 4.5. Significant differences P<0.05 in leaf greenness between five varieties at branching and flowering stage were observed. Varieties N26 and KS20 were greener than the other varieties. There were no significant differences observed in the merged data for the five varieties under the two tillage systems. No significant difference was observed in the interaction of five varieties and tillage systems.

Table 4.5. Leaf greenness (SPAD units) at 50% branching and flowering of five green gram varieties grown under different tillage system in Katumani and Kikesa during 2020 short rainsand 2021 long rains seasons

| Treatment | Katumani | | | | Kikesa | | | |
|---|---|---|---|---|---|---|---|---|
| | 2020 short rains | | 2021 long rains | | 2020 short rains | | 2021 long rains | |
| | Branch | Flower | Branch | Flower | Branch | Flower | Branch | Flower |
| Variety | | | | | | | | |
| N26 | 49.7a | 45.4a | 40.6a | 41.3a | 37.9a | 39.4a | 39.6a | 40.4a |
| KS20 | 45.1a | 44.2a | 38.8a | 40.1ab | 37.1a | 38.4a | 38.8a | 39.2a |
| Biashara | 30.5b | 32.5b | 36.2b | 38.0b | 35.8ab | 36.6ab | 37.2ab | 37.4a |
| Karembo | 38.4ab | 39.5ab | 37.4b | 38.9ab | 35.2b | 36.1b | 36.6b | 39.9a |
| Tosha | 39.5ab | 40.2a | 35.9b | 38.1ab | 35.9ab | 37.5a | 37.8a | 38.3a |
| P value | 0.028 | 0.014 | 0.01 | 0.059 | 0.039 | 0.055 | 0.094 | 0.07 |
| LSD | 11.5 | 7.2 | 2.7 | 2.5 | 1.9 | 2.4 | 2.4 | 2.6 |
| CV% | 7 | 5.3 | 3.9 | 2.7 | 3 | 2.9 | 3.1 | 2.7 |
| Tillage system | | | | | | | | |
| CT | 39.2a | 39.3a | 37.57a | 39.6a | 36.2a | 37.4a | 37.8a | 38.2a |
| NT | 42.1a | 41.4a | 37.73a | 39.0a | 36.5a | 37.8a | 38.2a | 38.7a |
| P value | 0.328 | 0.27 | 0.911 | 0.594 | 0.787 | 0.719 | 0.691 | 0.66 |
| LSD | 9.9 | 5.9 | 5.2 | 3.7 | 3.8 | 3.8 | 4.2 | 3.7 |
| CV% | 4.8 | 4.2 | 2.5 | 2.2 | 2.4 | 2.0 | 2.0 | 2.1 |
| Interactions (P values) | | | | | | | | |
| Variety× Tillage | 0.611 | 0.608 | 0.37 | 0.238 | 0.176 | 0.134 | 0.691 | 0.23 |

Means followed by the same letter within a column are not significantly different at P<0.05

### 4.4.5 Plant height

Table 4.6 presents plant height of green gram varieties and interaction with tillage system. The five varieties showed significant difference ($P<0.05$) in plant height. Variety N26 was the tallest variety, at branching and flowering stages, KS20 was the second tallest while the other varieties did not show any significant difference.

Significant differences ($P<0.05$) between two tillage systems were observed only in the first season at Katumani. Plants in the conventional tillage system were taller than those in the no till system. No significant differences were recorded on the interaction between the five varieties and tillage system.

Table 4.6. Plant height at 50% branching and flowering of five green gram varieties grown under different tillage system in Katumani and Kikesa during 2020 short rains and 2021 long rains seasons

| Treatment | Katumani | | | | Kikesa | | | |
|---|---|---|---|---|---|---|---|---|
| | 2020 short rains | | 2021 long rains | | 2020 short rains | | 2021 long rains | |
| | Bran | Flow | Bran | Flow | Bran | Flow | Bran | Flow |
| Variety | | | | | | | | |
| N26 | 19.3a | 21.4a | 26.0a | 27.8a | 20.3a | 22.0a | 20.6a | 20.9a |
| KS20 | 17.9a | 19.0b | 20.9b | 22.3b | 18.0b | 19.4bc | 18.3b | 18.7b |
| Biashara | 12.2b | 14.2c | 19.3c | 21.0b | 17.4b | 19.0bc | 17.7b | 18.1b |
| Karembo | 12.2b | 14.1c | 21.7b | 22.9b | 17.0b | 18.5c | 17.3b | 17.7b |
| Tosha | 14.0b | 15.7c | 21.3b | 22.7b | 19.4ab | 21.1ab | 19.7ab | 20.1a |
| P value | <0.001 | <0.001 | <0.001 | <0.001 | 0.015 | 0.011 | 0.015 | 0.015 |
| LSD | 2.0 | 1.9 | 1.6 | 1.8 | 2.0 | 2.1 | 2.0 | 2.0 |
| CV% | 6.3 | 5.4 | 4.8 | 4.8 | 5.9 | 7.3 | 7.2 | 7 |
| Tillage system | | | | | | | | |
| CT | 16.5a | 18.0a | 22.3a | 23.9a | 18.6a | 20.0a | 18.9a | 19.2a |
| NT | 13.6b | 15.8b | 21.4a | 22.8a | 18.3a | 20.0a | 18.6a | 19.0a |
| P value | 0.007 | 0.043 | 0.059 | 0.061 | 0.859 | 0.983 | 0.859 | 0.859 |
| LSD | 1.0 | 2.1 | 1.0 | 1.2 | 4.7 | 5.1 | 4.7 | 4.7 |
| CV% | 1.9 | 3.5 | 1.3 | 1.4 | 7.3 | 5.8 | 5.8 | 5.7 |
| Interactions (P values) | | | | | | | | |
| Variety× Tillage | 0.731 | 0.927 | 0.019 | 0.017 | 0.264 | 0.365 | 0.26 | 0.264 |

Means followed by the same letter within a column are not significantly different at $P<0.05$

### 4.4.6 Yield components

Tables 4.7 and 4.8 display varietal differences in green grams yield components and its interaction with tillage systems. The five varieties varied significantly ($P<0.05$) in total number of pods per plant, pod length and number of seeds per pod. Variety N26 had a higher number of pods per plant, longer pods and higher number of seeds per pod than the other four varieties which did not show any significant differences. No significant differences were observed between the two tillage systems as well as interaction between the five varieties and the tillage system.

Significant differences were observed between the five varieties in 100 seed weight. For instance, Biashara was heavier by 2.2 g than the other varieties in the first season while N26 was lighter. In the second season, varieties Biashara, Karembo and Ndengu Tosha were heavier than N26 and KS20. There was no significant difference in yield during the first season. In the second season, N26 had the highest yield compared to the four varieties in both Katumani and Kikesa. No significant difference was observed between the two tillage systems as well as interaction between varieties and tillage systems.

Table 4.7. Number of pods per plant, pod length (cm) and number of seeds per pod of five green gram varieties grown under the two tillage systems in Katumani and Kikesa during short and long rains

| | Katumani | | | | | | | Kikesa | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Treatment | 2020 short rains | | | 2021 long rains | | | | 2020 short rains | | 2021 long rains | | |
| | Pods | Length | Seeds | Pods | Length | Seeds | Pods | Length | Seeds | Pods | Length | Seeds |
| Variety | | | | | | | | | | | | |
| N26 | 6.8a | 9.3a | 11.4a | 8.1a | 8.0a | 8.0a | 7.1a | 7.8a | 8.7a | 7.6a | 7.8a | 8.3a |
| KS20 | 5.8b | 8.8b | 10.0b | 7.3a | 6.9b | 6.9b | 5.5b | 7.1b | 7.1b | 6.5b | 7.1a | 7.4b |
| Biashara | 5.3b | 8.2c | 7.4c | 6.8ab | 6.6b | 6.7b | 4.9b | 6.9b | 6.5b | 6.5b | 6.8ab | 6.9b |
| Karembo | 5.7b | 8.3c | 9.2b | 6.4b | 6.6b | 6.2b | 4.1b | 6.8b | 6.2b | 6.3b | 6.7b | 6.7b |
| Tosha | 5.5b | 8.0c | 8.7b | 6.5b | 6.8b | 6.8b | 5.5b | 7.4a | 6.5b | 6.0b | 7.3a | 6.7b |
| P value | 0.007 | <0.001 | <0.001 | 0.002 | <0.001 | 0.002 | 0.008 | 0.023 | 0.019 | 0.045 | 0.027 | 0.005 |
| LSD | 0.4 | 0.4 | 1.0 | 0.8 | 0.4 | 0.8 | 1.5 | 0.6 | 1.5 | 1.0 | 0.7 | 0.9 |
| CV% | 10.7 | 2.5 | 4.1 | 3.4 | 3.5 | 2.5 | 10.6 | 3.4 | 3 | 5.2 | 3.6 | 0.2 |
| Tillage system | | | | | | | | | | | | |
| CT | 6.1a | 8.6a | 9.5a | 6.9a | 7.0a | 7.0a | 5.3a | 7.2a | 7.2a | 6.9a | 7.2a | 7.1a |
| NT | 5.5a | 8.4a | 9.3a | 7.1a | 7.0a | 6.9a | 5.5a | 7.2a | 6.9a | 6.4a | 7.1a | 7.2b |
| P value | 0.376 | 0.3 | 0.61 | 0.26 | 0.944 | 0.478 | 0.662 | 0.832 | 0.219 | 0.22 | 0.82 | 0.02 |
| LSD | 2.2 | 0.7 | 1.3 | 0.9 | 0.9 | 0.6 | 2.0 | 0.9 | 0.8 | 1.2 | 0.9 | 0.1 |
| CV% | 2.6 | 2.5 | 5.3 | 1.3 | 0.3 | 4.7 | 11.6 | 0.3 | 7.3 | 1.1 | 0.4 | 2.5 |
| Interactions (P values) | | | | | | | | | | | | |
| Variety×Tillage | 0.233 | 0.899 | 0.863 | 0.848 | 0.793 | 0.803 | 0.986 | 0.995 | 0.861 | 0.95 | 0.937 | 0.926 |

Means followed by the same letter within a column are not significantly different at P<0.05

Table 4.8. One hundred seed weight, yield and harvest indices of five green gram varieties grown ontwo tillage system

| Treatment | Katumani | | | | | | Kikesa | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 2020 short rains | | | 2021 long rains | | | 2020 short rains | | | 2021 long rains | | |
| | Weight (g) | Yield (t/ha) | HI% | Weight (g) | Yield (t/ha) | HI% | Weight (g) | Yield (t/ha) | HI% | Weight (g) | Yield (t/ha) | HI% |
| Variety | | | | | | | | | | | | |
| N26 | 6.278c | 0.897a | 38.7a | 5.880b | 0.879a | 25.2a | 6.76b | 0.815a | 36.5a | 7.26b | 0.894a | 22.9a |
| KS20 | 7.332bc | 0.697b | 32.2a | 6.220ab | 0.747a | 24.9a | 8.16a | 0.683a | 31.4a | 8.18a | 0.688b | 20.3ab |
| Biashara | 8.375a | 0.606b | 28.4b | 6.880a | 0.654a | 21.9a | 8.90a | 0.575ab | 28.4a | 8.79a | 0.611b | 20.4ab |
| Karembo | 7.665b | 0.602b | 29.5b | 6.690a | 0.567b | 20.1a | 8.92a | 0.560ab | 29.5a | 8.60a | 0.582b | 18.6b |
| Tosha | 7.587b | 0.564b | 29.1b | 6.690a | 0.630ab | 24.3a | 8.68a | 0.550b | 28.1a | 8.40a | 0.628b | 20.5ab |
| P value | <0.001 | <0.001 | 0.041 | 0.008 | 0.034 | 0.554 | <0.001 | 0.026 | 0.097 | <0.001 | 0.002 | 0.039 |
| LSD | 0.285 | 0.131 | 7.0 | 0.547 | 0.201 | 7.0 | 0.35 | 0.182 | 7.0 | 0.6 | 0.140 | 2.6 |
| CV% | 0.5 | 11.0 | 6.2 | 1.7 | 22.0 | 11.1 | 1.2 | 16.2 | 14.8 | 0.8 | 16.9 | 7.5 |
| Tillage system | | | | | | | | | | | | |
| CT | 7.441a | 0.705a | 29.5a | 6.48a | 0.726a | 23.3a | 8.263a | 0.654a | 28.4a | 8.3a | 0.695a | 20.0a |
| NT | 7.454a | 0.641a | 33.7a | 6.47a | 0.665a | 23.3a | 8.303a | 0.619a | 33.1a | 8.3a | 0.666a | 21.1a |
| P value | 0.690 | 0.088 | 0.421 | 0.961 | 0.677 | 0.99 | 0.672 | 0.677 | 0.332 | 0.588 | 0.574 | 0.213 |
| LSD | 0.124 | 0.090 | 18.0 | 0.647 | 0.540 | 9.0 | 0.548 | 0.310 | 16.0 | 0.240 | 0.190 | 2.560 |
| CV% | 4.0 | 3.7 | 16.2 | 2.8 | 13.7 | 11.6 | 0.5 | 14.0 | 2.7 | 1.6 | 7.8 | 3.6 |
| Interactions (P values) | | | | | | | | | | | | |
| Variety×Tillage | 0.473 | 0.973 | 0.146 | 0.621 | 0.411 | 0.296 | 0.634 | 0.264 | 0.231 | 0.678 | 0.480 | 0.145 |

Means followed by the same letter within a column are not significantly different at $P<0.05$

## 4.5 Discussion

### 4.5.1 Effect of tillage system on crop phenology

While varietal differences in crop phenology were recorded among the selected green gram varieties. There were no significant differences observed between conventional and no tillage systems as well as interaction between variety and tillage system. Consistently, variety N26 was late maturing compared to KS20, Biashara, Karembo and Ndengu Tosha. Early maturity trait in a plant involves combination of early flower initiation and grain filling period (Bhavyasri et al., 2022). Variation in green gram development stages could be attributed to breeding advances to adapt the newer varieties to moisture stress and drought (Bhavyasri et al., 2022).

The impact of tillage practices on crop phenology and the interaction between crop varieties and tillage systems was not evident in the present study. However, it is noteworthy that Hakim et al. (2022) conducted a study that reported substantial differences in the growth and yield of green gram varieties when exposed to three distinct tillage methods-furrow ridge, zero tillage, and conventional tillage. This discrepancy in findings suggests that the influence of tillage on crop phenology and its interaction with specific varieties may vary across different studies and environmental conditions. While the current study did not observe such effects, the results from Hakim et al., (2022) underline the importance of considering diverse tillage methods and their potential implications for crop growth and yield. Further research may be needed to explore the nuanced interactions between tillage practices, crop phenology, and specific crop varieties to enhance our understanding of sustainable agronomic practices.

### 4.5.2 Effect of tillage system on crop growth

Varietal difference played a key role in plant height, number of branches and leaf greenness. Variety N26 was significantly taller with more branches per plant and higher leaf greenness measurement than the other varieties. This could be ascribed to soil moisture and genetic ability of varieties to grow and develop which could have caused the differences in crop growth traits. This finding agrees with (Mulika et al., 2022) who reported that growth parameters, like plant height vary significantly with variety. Tillage effects on plant height appeared in the first season of Katumani experiment, whereby plants under conventional tillage were taller by 4 cm compared to those under no tillage system. Loosening the soils through improved tillage increases soil proliferation of roots for uptake of water and nutrient.

These findings conform to the study done by Hakim et al., 2022 who reported high plant height recorded in deeply tilled plots.

### 4.5.3 Effect of tillage system on nodulation

Root nodulation in green gram is an important parameter associated with sustained performance under drought. Green gram has ability to fix atmospheric nitrogen through rhizobial species living the root nodules. This rhizobial species invade the root hairs resulting to formation of nodules. Nitrogen fixation solicit crop growth and yield of legumes (Goyal et al., 2021). VarietyN26 had the highest number of total nodules at branching compared to the other varieties. At flowering N26 and KS20 recorded more nodules and active nodules than Biashara, Karembo andNdengu Tosha. This variation in nodulation among green gram varieties could be associated withgenetic variation. According to study by Goyal et al., (2021), rhizobial species are host specific and interact variably with different genotypes of same species. This variation in the root interaction with rhizobial species and nodulation is important to plant breeders in execution of breeding program. Green gram plants grown under conventional tillage system had a higher number of nodules than those grown in no tillage plots. This could be associated with soil porosity and compaction. Compacted soil may pose a huge challenge on the root traits such reduction in root length and root density, which could limit the number of available potential infection sites by rhizobia as a result of high bulk. These findings agree with study conducted by Burghardt et al., (2021) which showed that soybean produce low numbers of nodules in high bulk density soils compared with low bulk density soils.

### 4.5.4 Effect of tillage on yield

Variety N26 exhibited superior traits, boasting the highest count of pods per plant, longer pods, a greater number of seeds per pod, and ultimately, a higher grain yield compared to other varieties. These distinctions in yield components likely stem from genetic variations inherent to this specific variety. These results align with Hakim et al.'s (2022) findings, which also noted significant differences in grain yield among various green gram varieties. Similarly, Mulika et al. (2022) reported comparable results.

Despite being a late-maturing variety, N26 demonstrated remarkable high yields in contrast to other varieties. This contradicts the conventional notion suggested by Baum et al. (2019) that early maturing varieties typically yield lower dry matter and grain compared to their late-maturing counterparts. This suggests that while maturity timing often influences yield, exceptions like N26 challenge these general trends, indicating the complexity of yield determinants beyond mere maturation timing.

### 4.6 Conclusions

Selected green gram varieties showed significant differences in their adaptation to tillage systems. Crop phenology, morphological traits and yield components varied significantly among the varieties. Generally, N26 was outstanding in crop performance, nodulation, plant height, leaf greenness, pods per plant and yield yet it matured late. Focus to adapt early maturing varieties Karembo, Biashara and Ndengu Tosha to no-tillage systems while improving yield is crucial. Crops grown under conventional tillage performed better with higher yield than those under no-tillage system. Additionally, there were no significant interactions between variety and tillage systems. This indicates that green gram breeding efforts have not prioritized selection for adaptation to no-tillage systems. Hence, additional research is required to explore the traits of green gram and mechanisms regulating their response to no tillage systems.

# CHAPTER FIVE: GENERAL DISCUSSION, CONCLUSIONS AND RECOMMENDATIONS

## 5.1 General discussion

Crop phenology, crop growth traits, nodulation and yield components varied significantly among the selected green gram varieties under varying moisture regimes of 40%, 60%, 80% and 100% FC as well as no tillage and conventional tillage systems. Varieties varied significantly ($P<0.05$).in number of days to 50% branching, flowering, podding and physiological maturity. While Biashara matured early N26 matured late, KS20, Karembo and Ndengu Tosha were intermediate. According to Farooq et al., (2020), early maturity is an important trait for adaptation of green gram to moisture stress since it is a mechanism for  legumes to escape drought that may set in during crop growth. Late maturity in variety N26 could be attributed to genetic variations of varieties (Mulika et. al., 2022.

Additionally, N26 showed more superior crop growth traits in plant height, leaf greeness and number of branches per plant under varying moisture regimes and no tillage system. It was the tallest variety with highest SPAD units recorded among the varieties across all four moisture regimes and no tillage system. However, varieties grown under 100% field capacity were taller while those at 40% were shorter. This may be because of moisture stress limiting crop growth traits (Kapoor et al., 2020). Consequently, varieties grown under conventional tillage system were taller compared to those under no-tillage. This may be as a result of good root proliferation under conventional tillage compared to no-tillage system with residue retention due to deep and fine tillage in conventional tillage, this enables the roots of the plants to uptake water and nutrients easily from the soil for crop growth and photosynthesis (Ramadhan and Muhsin, 2021)

Varying moisture regime and no tillage system had significant effect on nodulation among the selected green gram varieties. Number of nodules and active nodules recorded in variety N26 were greater in number compared to the other varieties. Varieties grown under 40% moisture regime had the lowest number of nodules and active nodules, this may have resulted from moisture stress limiting nodulation process. Additionally, lower number in nodules could have resulted to inferior crop performance and yield observed in all the five varieties that were grown under this moisture regime since nitrogen plays an important role in growth and development of plants (Islam et al., 2022).

Low number of nodules were also recorded among the varieties grown under no tillage system compared to conventional tillage. This may be as a result of compacted soils under the no tillage system, limiting the root growth and proliferation which impacts the process of nodulation (Ramadhan and Muhsin, 2021).

Yield varied significantly among the green gram varieties grown under varying moisture regimes and no tillage system. This variation included number of pods per plant, numbers of seeds per pod, seed weight and the average yield per variety. Variations in yield components could be attributed to response of the selected varieties to varying moisture levels and no tillage systems with residue retention. N26 showed highest number of pods as well as yield in both experiments. Variations among the varieties could be attributed to genotypic differences (Mulika et. al., 2022). N26 being the high yielding variety contrast with other varieties even though it matured late, this agrees with Baum et al., (2019) that early maturing varieties produce low yield compared to late maturing crops this is as a result of minimum time used for dry matter accumulation and partitioning in early maturing crops. Lower yield was recorded under 40% field capacity and no tillage. Moisture stress is the most limiting factor in crop production.

## 5.2 Conclusions

Green gram varieties varied significantly on the phenology and morphological traits under varying moisture regimes and tillage systems. Variety N26 and KS20 recorded superior morphological traits for number of nodules, active nodules, plant height, number of pods per plants, number of seeds per pods and yield hence may be used in improving new released green gram varieties to achieve higher yield. The lowest moisture level of 40% FC had a negative impact on crop performance and yield, crops under this level recorded low number of nodules, plant height and number of pods per plant. Variations among selected green gram varieties underfour moisture regimes 40%, 60%, 80% and 100% FC presents a great possibility for the development of suitable varieties for various agro-ecological zones. Released varieties should be evaluated to determine their response to moisture stress.

Crops under conventional tillage performed better compared to those under no-tillage system. These observed variations among green gram varieties in the two tillage systems show that more focus in the future should be on how selected varieties adapt to tillage systems, particularly no tillage system as a soil moisture conservation method in the arid and semi-arid regions.

## 5.3 Recommendations

1. Conduct additional research to investigate how green gram varieties adapt to diverse moisture levels.

2. Explore the adaptability of released green gram varieties to no-tillage and residue retention systems through further studies.

3. Investigate the interaction between different green gram varieties and various moisture regimes to comprehend how these varieties respond to moisture stress.

4. Further research is necessary to delve into the relationship between tillage systems and the growth characteristics of green gram varieties, enhancing our knowledge of sustainable agricultural practices.

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# APPENDICES

Appendix 1. Analysis of variance for number of nodules at 50% branching of green gram in Kabete during 2020 experiment cycle 1

| Source of variation | d.f. | s.s. | m.s. | v.r. | F pr. |
|---|---|---|---|---|---|
| Rep stratum | 2 | 19.30 | 9.65 | 0.83 | |
| | | | | | |
| Rep.*Units* stratum | | | | | |
| FC | 3 | 303.07 | 101.02 | 8.65 | <.001 |
| Variety | 4 | 144.57 | 36.14 | 3.09 | 0.027 |
| FC. Variety | 12 | 225.43 | 18.79 | 1.61 | 0.131 |
| Residual | 38 | 444.03 | 11.69 | | |
| | | | | | |
| Total | 59 | 1136.40 | | | |

Appendix 1. Analysis of variance for number of nodules at 50% branching of green gram in Kabete during 2021 experiment cycle 2

| Source of variation | d.f. | s.s. | m.s. | v.r. | F pr. |
|---|---|---|---|---|---|
| Rep stratum | 2 | 18.03 | 9.02 | 0.86 | |
| | | | | | |
| Rep.*Units* stratum | | | | | |
| FC | 3 | 329.80 | 109.93 | 10.51 | <.001 |
| Variety | 4 | 131.07 | 32.77 | 3.13 | 0.025 |
| FC. Variety | 12 | 158.53 | 13.21 | 1.26 | 0.279 |
| Residual | 38 | 397.30 | 10.46 | | |
| | | | | | |
| Total | 59 | 1034.73 | | | |

Appendix 2. Analysis of variance for seed yield of green gram in Katumani during 2020 short rains

| Source of variation | d.f. | s.s. | m.s. | v.r. | F pr. |
|---|---|---|---|---|---|
| Block stratum | 2 | 0.11011 | 0.05506 | 17.71 | |
| | | | | | |
| Block.Main_plot stratum | | | | | |
| Tillage | 1 | 0.03088 | 0.03088 | 9.93 | 0.088 |
| Residual | 2 | 0.00622 | 0.00311 | 0.27 | |
| | | | | | |
| Block.Main_plot. Sub_plot stratum | | | | | |
| Variety | 4 | 0.43407 | 0.10852 | 9.42 | <.001 |
| Tillage.Variety | 4 | 0.00562 | 0.00140 | 0.12 | 0.973 |
| Residual | 16 | 0.18431 | 0.01152 | | |
| | | | | | |
| Total | 29 | 0.77120 | | | |

Appendix 3. Analysis of variance for seed yield of green gram in Katumani during 2021 long rains

| Source of variation | d.f. | s.s. | m.s. | v.r. | F pr. |
|---|---|---|---|---|---|
| Block stratum | 2 | 0.18104 | 0.09052 | 0.77 | |
| | | | | | |
| Block.Main_plot stratum | | | | | |
| Tillage | 1 | 0.02720 | 0.02720 | 0.23 | 0.677 |
| Residual | 2 | 0.23400 | 0.11700 | 4.52 | |
| | | | | | |
| Block.Main_plot. Sub_plot stratum | | | | | |
| Variety | 4 | 0.35335 | 0.08834 | 3.41 | 0.034 |
| Tillage.Variety | 4 | 0.10909 | 0.02727 | 1.05 | 0.411 |
| Residual | 16 | 0.41389 | 0.02587 | | |
| | | | | | |
| Total | 29 | 1.31857 | | | |

Appendix 4. Analysis of variance for seed yield of green gram in Kikesa during 2020 short rains

| Source of variation | d.f. | s.s. | m.s. | v.r. | F pr. |
|---|---|---|---|---|---|
| Block stratum | 2 | 0.21234 | 0.10617 | 2.68 | |
| | | | | | |
| Block.Main_plot stratum | | | | | |
| Tillage | 1 | 0.00922 | 0.00922 | 0.23 | 0.677 |
| Residual | 2 | 0.07926 | 0.03963 | 1.91 | |
| | | | | | |
| Block.Main_plot. Sub_plot stratum | | | | | |
| Variety | 4 | 0.30606 | 0.07651 | 3.68 | 0.026 |
| Tillage.Variety | 4 | 0.12030 | 0.03008 | 1.45 | 0.264 |
| Residual | 16 | 0.33246 | 0.02078 | | |
| | | | | | |
| Total | 29 | 1.05963 | | | |

Appendix 5. Analysis of variance for seed yield of green gram in Kikesa during 2021 long rains

| Source of variation | d.f. | s.s. | m.s. | v.r. | F pr. |
|---|---|---|---|---|---|
| Block stratum | 2 | 0.26302 | 0.13151 | 9.32 | |
| | | | | | |
| Block.Main_plot stratum | | | | | |
| Tillage | 1 | 0.00626 | 0.00626 | 0.44 | 0.574 |
| Residual | 2 | 0.02823 | 0.01411 | 1.02 | |
| | | | | | |
| Block.Main_plot. Sub_plot stratum | | | | | |
| Variety | 4 | 0.37705 | 0.09426 | 6.83 | 0.002 |
| Tillage.Variety | 4 | 0.05041 | 0.01260 | 0.91 | 0.480 |
| Residual | 16 | 0.22080 | 0.01380 | | |
| | | | | | |
| Total | 29 | 0.94578 | | | |