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Research Article

Effect of Tillage Method and Mulch Application on Growth and Yield of Green Gram in Semiarid Kenya

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Conservation tillage is regarded as the best practice for crop production in drylands. However, their effect on the green gram (*Vigna radiata* (L) Wilczek) has not been much documented in ASALs of Kenya. A field study was conducted during the 2018-2019 short rains with the aim of evaluating the effect of tillage methods and mulch application on the growth and yield of two green gram varieties in Katumani and Mwea. A randomized complete block design (RCBD) with a split-slit plot arrangement and three replicates was used. The main plots were tillage methods zero tillage (ZT), furrow-ridge (FR), and conventional tillage (CT). Subplots were mulched plots with plant residue (3 $t{\cdot}ha^{-1}$) and plots without mulch applied (0 $t{\cdot}ha^{-1}$) and in the sub-subplots were two green gram varieties (N26 and KS20). Data was collected on plant height, number of primary branches, root biomass, shoot biomass, number of pods per plant, number of seeds per pod, 1000 seed weight, grain weight ($t{\cdot}ha^{1}$), and harvest index. Data was subjected to the general analysis of variance using GenStat 15th statistical software. Mean separation was calculated using the least significant difference LSD at a 5% probability level. Results showed that tillage methods and mulch application significantly affected growth, yield, and yield component. Furrow-ridge recorded superior effects ahead of zero tillage and conventional tillage. Mulch application had significant effects on growth, yield, and yield component. Variety N26 under the treatment of furrow-ridge mulched with 3 $t{\cdot}ha^{-1}$ had a greater number of branches, plant height, yield, and yield components in both experiment sites. The application of mulch had a positive impact on growth, yield, and yield component. Furrow-ridge and zero tillage with mulch emerged to be the most efficient techniques for better green gram yield in Katumani and Mwea. This can be recommended for increased crop production in areas that receive insufficient rainfall.

1. Introduction

Green gram is majorly grown in the arid and semiarid lands in Kenya but faces many production constraints [1]. The key production challenge to green gram production is low and unreliable rainfall [2]. Climate change and variability are the cause of unreliable and even rainfall in Kenya which continue to affect crop yield across the region, especially in the east and some parts of central and western Kenya [3].

Low crop yield in the arid and semiarid lands of Kenya has been attributed to low and unreliable rainfall [4, 5]. The arid and semiarid land (ASAL) regions in Kenya experience high evapotranspiration of about 2000–2300 mm/year [6] which affects soil moisture conservation. The soil in these areas has shallow and poor structural stability which makes it easily erodible with low soil nutrient content [7]. The conservation of soil moisture through better tillage practices impacts crop production in arid and semiarid areas [4]. Therefore, under average conditions, conservation agriculture increases crop yield by 4.6% [8]. It has been documented that zero tillage, furrow-ridge, and mulch conserve soil moisture and soil nutrient [9, 10]. Crop yield is influenced by soil nutrients and moisture under zero tillage and furrow-ridge increase comparably to nonconservation techniques [11]. Soil erosion is mild under zero tillage with increased soil organic matter and water infiltration [12]. Mulch application and use of appropriate mulch increases crop yield and improves water use efficiency [13].

It has also been documented that mulch reduces weeds infestation which competes with crops for, moisture, nutrient, and light (Siipilehto) [14, 15].

The use of tillage practices like zero tillage, furrow-ridge, and mulching was seen to improve crop productivity and soil moisture retention. However, limited studies have been established on whether these improved tillage practices on green gram productivity in semiarid Kenya.

Therefore, this study was to evaluate the effect of contrasting tillage methods and mulch effect on green gram productivity in semiarid Kenya.

2. Materials and Methods

2.1. Experimental Sites. The experiments were conducted at the Kenya Agricultural and Livestock Research Organization (KALRO) research stations in Katumani and Mwea during the 2018/2019 short rains season (Figure 1). The center lies between latitudes 1°35′ S and longitude 37°14′, at an elevation of 1575 meters above sea level. The area falls under agroclimatic zone IV [16]. The mean maximum and minimum air temperatures are 24.6 and 13.7°C, respectively. The mean potential evaporation ranges from 1820 mm to 1840 mm with estimated evapotranspiration (ET_o) of 1239 mm per year [17].

The predominant soil types are Ferralo-Chromic Luvisols [18], having poor structure, high sand, and low clay content and exhibiting high bulk density [19, 20].

KALRO Mwea is located on 0°38′S latitude and 37°22′E longitude, at an elevation of approximately 1150 m above sea level (Figure 1). This research experiences a bimodal rainfall regime with an annual mean of 850 mm. The long rains occur from March to May while short rains are between October and December. The annual maximum and minimum temperatures recorded at the station are 28.6°C and 15.6°C, respectively. It has vertisol soils with an acidic pH of about 5.1.

2.2. Treatments and Experiment Design. The experiment contained six treatments which included conventional tillage with 0 t ha^{-1} of mulch, conventional tillage with 3 t·ha^{-1} of mulch, furrow-ridge with 0 t·ha^{-1} of mulch, furrow- ridge with 3 t·ha^{-1} of mulch, zero tillage with 0 t·ha^{-1} of mulch, and zero tillage with 3 t·ha^{-1} of mulch. Each treatment was tried with two green gram varieties, KS20 and N26.

Treatments were laid out in an RCBD in a split-split plot design with tillage in the main plot; mulch application in the subplot and in the sub-subplot was the variety replicated three times. The sub-subplot measured 5 m × 2.25 m and the total area covered by the entire experiment was 760.5 m^2 with 2 m between blocks and 1 m between plots. The main plots contained the three tillage practices conventional tillage, furrow-ridge, and zero tillage, and in the subplot, there was a mulched plot with 3 t·ha^{-1} of plant residue and plots with 0 t·ha^{-1} or no mulch applied. Finally, in the sub-subplot were two improved drought-tolerant green gram varieties KS20 that matures and N26 that matures all released from the KALRO station in Katumani.

2.3. Experiment Management. Land preparation in conventional tillage was prepared by simple hand hoe and the soil was prepared to a finer seedbed. In zero tillage, plots were prepared by slashing the field to ground level; then, Dual Gold 960EC at the rate of 4 L·ha^{-1} was applied to kill weeds two weeks before planting without disturbing the soil while in furrow-ridge, plots were prepared by heaping heels to a height of 20 cm and width of 45 cm from between heels by simple hand hoe and seeds planted on the heels. Soil fertility analyses were done before planting to ascertain the nutrient content of the soil from the two sites at the National Agricultural Research Laboratories (NARL) (Table 1). The fertilizer application was based on soil analysis results and recommendations from the two field sites. In Mwea, 140 kg/acre of N: P: K 17:17:17 fertilizer and 2 tons of well-decomposed cow manure were applied while in Katumani, only 4 tons of well-decomposed cow manure was applied (Table 1). Three green gram seeds were sown per hole at the onset of rains at spacing of 45 cm between rows and 20 cm between plants at a depth of 4 cm and later thinned to a plant per station. Application of the 3t ha^{-1} of mulch was done after planting in plots with mulch inclusive in the treatment. Powdery mildew was controlled using ABSOLUTE 375SC 10 ml/20l and common pest such as thrips was controlled by spraying using TRACER 480SC which contain active Spinosad ingredients.

Figure 1 illustrates the map of the study area of Katumani and Mwea where the experiments were conducted.

Rainfall in Katumani and Mwea has always been low with an average rainfall of 294.2 mm and 327 mm, respectively (Table 2). The short rain of 2018/2019 was low in the two sites with Mwea recording the lowest mean monthly rainfall of 36.4 mm and Katumani 81.6 mm (Table 2). The rain started in Mid-October 2018 and extended till February 2019, and the highest rainfall was recorded in December in Katumani and in November in Mwea with the lowest in February in Katumani and January in Mwea (Table 2). Temperatures in Mwea have been higher with an average temperature of 31°C and 31.3°C between February and March (Table 2). High relative humidity was recorded in Mwea at 77% and the lowest in Katumani at 58.2% in February while in Mwea the highest humidity was 76.03 and the lowest was 60.8% (Table 2).

2.4. Data Analysis. Data on phenology, growth, yield, and yield components were subjected to the general analysis of variance using GenStat 15th statistical software (Payne et al., 2005). Mean separation was calculated using the least significant difference LSD at a probability level of 5%.

2.4.1. Growth Parameters. Plant height was taken from 5 randomly selected green gram plants at two different growth stages: vegetative (30 days after planting) and flowering (45 days after planting) from each plot under each treatment using a meter rule and average height recorded.

The number of primary branches was recorded by counting the number of branches from five randomly selected plants in each plot under each treatment at harvest.

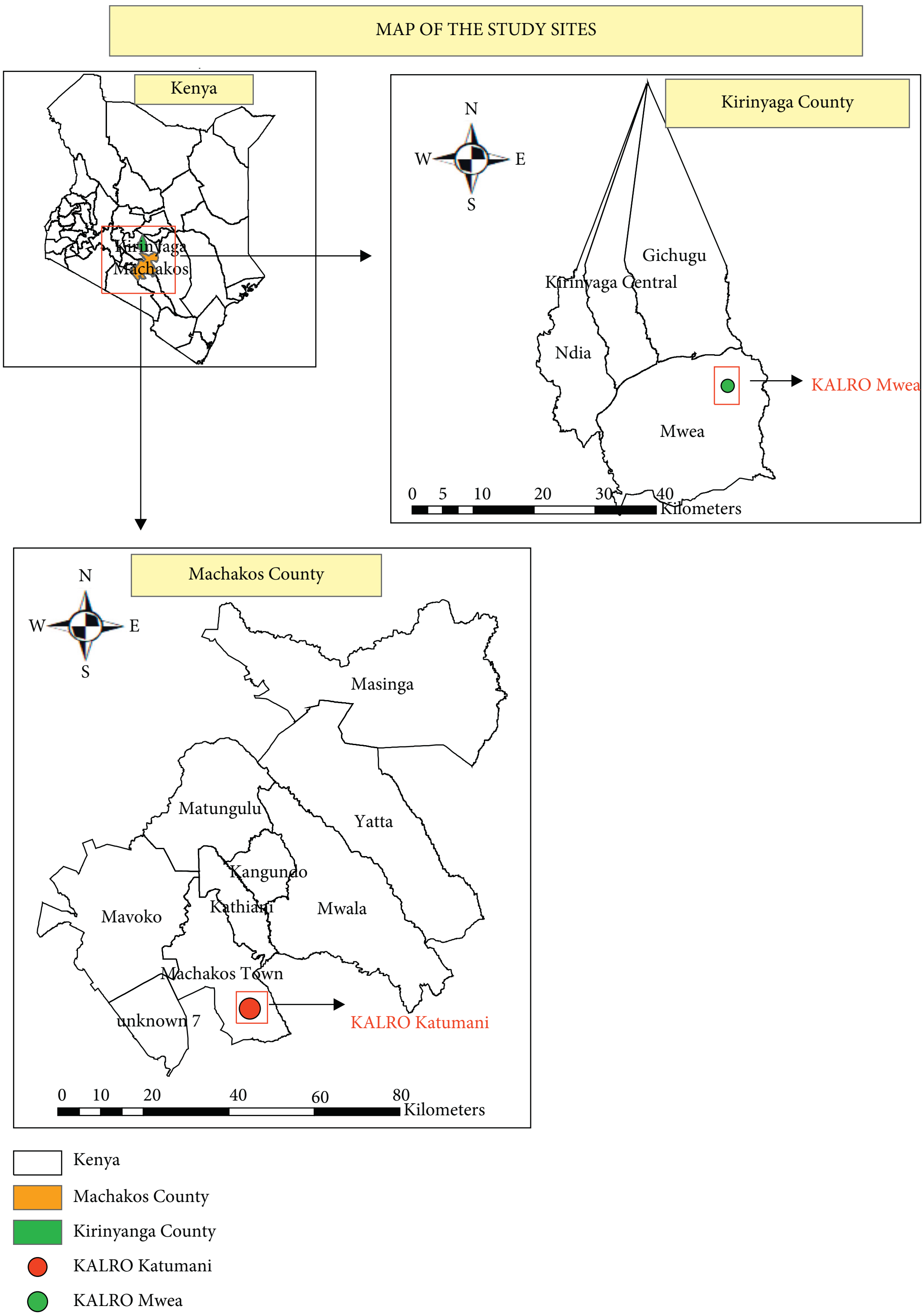

Figure 1: Map of the study sites. Data collection weather data.

Data on root biomass was taken by random sampling of five plants at the flowering and maturity stage by cutting plant roots above the ground at the base of the plant stem. Watering was done at the base of the plant before a gentle uprooting of the plant was done to get out all the plant roots. The collected roots were cut and placed in the oven at a temperature of 70 C for 48 hours until they attained dry weight. The dry weight in grams per hectare was then recorded.

Biomass data was collected from 5 randomly selected plants at maturity and then placed in an oven at a temperature of 70°C for 48 hours till dry weight was achieved.

Table 1: Baseline of soil chemical properties in Katumani and Mwea.

KALRO Katumani Fertility results	Value	Class	KALRO Mwea Value	KALRO Mwea Class
Soil Ph	6.36	slight acid	5.85	medium acid
Total nitrogen %	0.1	low	0.13	low
Total organic carbon %	0.82	low	1.45	moderate
Phosphorus ppm	150	high	15	low
Potassium ppm	84	adequate	35	low
Calcium me%	6.6	adequate	2.6	adequate
Magnesium me%	4.81	high	1	adequate
Manganese me%	0.31	adequate	0.46	adequate
Copper ppm	1.5	adequate	1.33	adequate
Iron ppm	14.3	adequate	16.6	adequate
Sodium me%	0.4	adequate	0.12	adequate

Table 2: Rainfall. Temperature and relative humidity of the two study sites (Mwea and Katumani).

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

R = rainfall, T = temperature, and H is humidity.

The yield and yield component included the number of pods per plant which was done by counting the number of pods from five randomly selected plants and the average was recorded at each plot.

The number of seeds per pod was determined by a random selection of 10 pods from a plot and the number of seeds counted and the average number of seeds per pod recorded.

Thousand (1000) seed weight data was recorded after pods were threshed and winnowed, a thousand seeds were counted randomly and weighed using an electric weighing balance, and weight was recorded in grams for each plot for Katumani and Mwea.

Grain yield per hectare ($t{\cdot}ha^{-1}$) data was collected from a net plot measuring 4.2×1.35 m after harvested pods were gently threshed and winnowed, and weight was recorded in tons per hectare.

The harvest index was calculated from the yield of green gram grains t·ha-1 and the Stover yield t·ha-1 from the two experimental sites.

2.5. Data Analysis. Data on growth, yield, and yield components were subjected to the general analysis of variance using GenStat 15th statistical software. Mean separation was calculated using the least significant difference LSD at a probability level of 5%.

3. Results

3.1. Effects of Tillage Methods and Mulch Application on Crop Growth Traits. Plant height at vegetative and flowering stages and the number of branches were influenced by tillage methods and mulch application. Table 3 indicated that plant height was significantly ($P \le 0.05$) affected by tillage methods and mulch application. Maximum plant height (44.04 cm) was recorded in furrow-ridge followed by conventional tillage (39.21 cm) and zero tillage (37.81 cm). Furthermore, significant plant height differences were noted in plot where 3 $t{\cdot}ha^{-1}$ of plant residues was added. Green grams grown under mulch were significantly taller (5.4 cm) and (4.5 cm) than green gram grown under no-mulch in the two sites, respectively. There was no significant ($P \ge 0.05$) varietal difference in plant height in both sites. No significant interaction was reported to affect green gram height in both sites. Similarly, at the flowering stage, green gram height varied significantly ($P \le 0.001$) with variety and high green gram plant height being recorded under furrow-ridge mulched with 3 t ha^{-1}plant residues compared to conventional and zero tillage methods.

The number of branches varied significantly ($P = 0.005$) with tillage methods in Katumani but not in Mwea. Green grams grown under furrow-ridge recorded a greater number of branches compared to those in conventional and zero tillage. Additionally, mulching played a role in influencing the number of branches in both sites. More branches were noted with the addition of 3 $t{\cdot}ha^{-1}$ in both Katumani and Mwea.

The number of branches varied significantly ($P < .001$) with variety in Katumani and Mwea. More number of branches was recorded with variety N26 compared to variety KS20 as indicated in Table 3.

No significant ($P \ge 0.05$) effect on the number of branches was recorded with tillage, mulch, variety, and interactions.

3.2. Effects of Tillage Methods and Mulch on Root Biomass at Flowering and Maturity. Green gram root biomass recorded at flowering and maturity varied significantly ($P \le 0.05$) with tillage methods and mulch application (Table 4). Root

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

Treatments and interactions	Katumani			Mwea		
	CHV	CHF	NB	CHV	CHF	NB
Tillage method						
Conventional tillage	39.21b	49.92b	4b	32.79b	47.33b	3.00a
Furrow-ridge	44.04a	60.35a	5a	36.76a	55.18a	3.00a
Zero tillage	37.81b	47.50c	4b	30.95b	39.70c	4.00a
LSD	3.35	1.88	0.19	2.77	4.25	0.65
P value	0.014	<.001	0.005	0.01	0.001	0.529
Mulch						
0 t·ha^{-1}	37.65b	58.69b	4.00b	31.26b	44.02b	4.00b
3 t·ha^{-1}	43.06a	66.77a	5.00a	35.74a	50.79a	5.00a
LSD	0.67	0.84	0.33	1.38	3.00	0.49
P value	0.014	<.001	0.004	<.001	0.001	0.008
Variety						
KS20	40.50a	65.13a	4.00b	33.85a	49.23a	3.00b
N26	40.21a	60.33b	5.00a	33.15a	45.58b	5.00a
LSD	0.62	0.78	0.17	0.78	0.78	0.30
P value	0.319	<.001	<.001	0.075	<.001	<.001
Interactions						
Tillage x mulch	0.014	0.003	0.373	0.196	0.446	0.609
Tillage x variety	0.338	0.020	0.262	0.564	0.917	0.848
Mulch x variety	0.834	0.242	0.493	0.490	0.762	1.000
Tillage x mulch x variety	0.123	0.248	0.001	0.950	0.293	0.619

LSD is the least significant difference; CHV = crop height at vegetative, CHF = crop height at flowering, NB = number of branches and means followed by the same letter are not significantly different at $P \leq 0.05$.

Table 4: Root biomass of green gram under contrasting tillage method and mulch in Katumani and Mwea.

	Katumani		Mwea	
	Flowering	Maturity	Flowering	Maturity
Tillage method				
Conventional tillage	1.92b	3.72b	1.59b	3.60b
Furrow-ridge	2.59a	4.50a	1.88a	3.98a
Zero tillage	2.03b	3.21c	1.56b	3.45b
LSD	0.25	0.37	0.214	0.36
P-value	0.004	0.001	0.03	0.033
Mulch				
0 t·ha^{-1} mulch	1.69b	3.38b	1.32b	3.30b
3 t·ha^{-1} mulch	2.67a	4.30a	2.03a	4.06a
LSD	0.10	0.41	0.11	0.22
P-value	<.001	0.001	<.001	<.001
Variety				
KS20	2.16a	3.83a	1.67a	3.66a
N26	2.20a	3.85a	1.69a	3.70a
LSD	0.08	0.10	0.25	0.05
P-value	0.343	0.787	0.133	0.158
Interactions				
Tillage × Mulch	0.003	0.144	0.283	0.348
Tillage × Variety	0.798	0.927	0.475	0.493
Mulch × Variety	0.072	0.991	0.096	0.929
Tillage × Mulch × Variety	0.377	0.647	0.696	0.072

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

biomass recorded under furrow-ridge was significantly higher than root biomass under conventional and zero tillage in both sites (Table 3). A similar trend was observed at the maturity stage. It was also noted that the addition of mulch significantly ($P < .001$) influenced the root biomass (Table 4). Significantly high root biomass was recorded in plots mulched with 3 t·ha^{-1} than in those without mulch (Table 3). There was no significant ($P = 0.343$) difference in root biomass recorded in the two green gram varieties at both growth stages (Table 4).

There was no significant effect recorded in tillage°×°variety, mulch°×°variety, and tillage°×°mulch tillage × variety interactions at flowering and maturity stages in both sites, but the interaction between tillage°×°mulch had a significant effect on root biomass at the flowering stage in Katumani (Table 4).

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

3.3. Effects of Tillage Method and Mulch Application on Yield and Yield Components. Statistical analysis of data showed that tillage methods and mulch application significantly ($P \leq 0.05$) affected the number of pods per plant in Katumani and Mwea (Table 5). The maximum number of pods per plant was recorded (61 pods) in furrow-ridge followed by (48 pods) in zero tillage and least in conventional tillage (41 pods) (Table 5). A similar trend was reported in Mwea with tillage methods (44 pods, 40 pods, and 39 pods, respectively) (Table 5). Maximum pods per plant were exhibited because of the addition of 3 t·ha^{-1} of mulch compared to those treatments without mulch (Table 5). It was also noted that the number of pods per plant varied significantly ($P < .001$) with variety (Table 5). Variety N26 recorded more pods per plant (53 pods) compared to KS20 (43 pods) (Table 5). In Katumani, the number of pods per plant was significantly ($P = 0.03$) affected by the interactions between tillage and variety (Table 5). More pods were recorded in variety N26 under furrow-ridge and least in KS20 under conventional tillage, and a similar trend was recorded in Mwea (Table 5). No significant effect was recorded between interactions in Katumani, but in Mwea, the number of pods per plant was significantly ($P = 0.01$) affected by the interaction between mulch and variety (Table 5). Variety N26 under 3 t·ha^{-1} of mulch recorded a greater number of pods (57 pods) with the lowest recorded in variety KS20 without mulch (Table 5). The interaction between tillage and mulch, tillage°×°variety, and tillage°×°mulch°×°variety did not have a significant effect on the number of pods per plant (Table 5).

The number of seeds per pod varied significantly with variety ($P < .001$) in Katumani and Mwea. Variety N26 recorded more seeds compared to variety KS20 in both sites (Table 5). However, tillage, mulch, and interactions did not have significant ($P > 0.05$) effects on the number of seeds per pod (Table 5).

Tillage methods significantly ($P < .001$) affected thousand (1000) seed weight in Katumani but did not have a significant effect in Mwea (Table 5). The maximum seed weight was recorded in furrow-ridge at 71.35 g and the lowest (55.54 g) in conventional tillage (Table 5). Mulching significantly affected the thousand seed weight in both sites. High weight from thousand seed weight (4 g and 5.72 g) was recorded in plots with 3 t ha $^{-1}$ of plant residue in Katumani and Mwea, respectively (Table 4).

Similarly, 1000 seed weight varied significantly ($P \leq 0.05$) with variety (Table 5). In Katumani, variety KS20 weighed (3 g) more than N26 and (6°g) more in Mwea (Table 5). The interaction between tillage°×°mulch°×°varieties significantly ($P \leq 0.05$) affected thousand seed weight in Mwea, but this was not the case in Katumani (Table 5). Variety KS20 under furrow-ridge mulched with 3 t·ha^{-1} recorded the highest seed weight, with the lowest weight recorded in N26 under conventional tillage with no mulch (Table 5).

It was also noted that tillage°×°mulch, tillage°×°variety, and mulch°×°variety did not significantly affect thousand seed weight in the two sites (Table 5).

Tillage method and mulch application significantly ($P < .001$) affected grain yield in Katumani and Mwea (Table 6). Furrow-ridge recorded a higher grain yield (1.09 t·ha^{-1}) compared to zero tillage (1.01 t·ha^{-1}) and the least in conventional tillage (0.93 t·ha^{-1}) in Katumani, with a similar trend recorded in Mwea (Table 6). Plots with 3 t·ha^{-1} of plant residues recorded higher grain yield (0.14 t·ha^{-1} and 0.16 t ha^{-1}) compared to those without mulch in Katumani and Mwea, respectively (Table 6).

Grain yields varied significantly ($P \leq 0.05$) with variety in both sites (Table 6). Variety N26 recorded a higher yield of 0.13 t·ha^{-1} and 0.1 t ha^{-1} than KS20 in Katumani and Mwea, respectively (Table 6).

In Katumani, the interaction between tillage°×°variety, mulch°×°variety, and tillage°×°mulch°×°variety had a significant ($P \leq 0.05$) effect on grain yield but tillage°×°mulch did not significantly affect the grain yield (Table 6).

Variety N26 grown under furrow-ridge mulched with 3 t·ha^{-1} of plant residue recorded a higher gain yield, compared to variety KS20 under conventional tillage with no mulch (Table 6). In Mwea, no significant interactions were reported (Table 6).

Biomass at harvest was significantly ($P \leq 0.05$) affected by the tillage method and mulch in Katumani and Mwea (Table 6). Furrow-ridge recorded maximum biomass (3.63 t·ha^{-1}) followed by zero tillage (3.22 t·ha$^{-1)}$ and minimum in conventional tillage (3.13 t·ha^{-1}) in Katumani, and a similar trend was recorded in Mwea (Table 6). The addition of 3 t·ha^{-1} plant residues increased the biomass by 0.52 t·ha^{-1} in Katumani and 0.59 t·ha^{-1} in Mwea (Table 6). Biomass at harvest varied significantly ($P < .001$) with variety in both sites. Variety N26 recorded high biomass (0.46 t·ha^{-1}) in Katumani and (0.37 t·ha^{-1}) in Mwea compared to KS20 (Table 6). Significant effects on biomass were recorded with the interaction of tillage°×°mulch and tillage°×°mulch°×°variety in Katumani but tillage°×°variety and mulch°×°variety did not have a significant effect on biomass (Table 6). No significant effect of interaction on biomass was noted in Mwea (Table 6).

Results showed that tillage methods and mulch application had no significant effect on the harvest index of green grams in Katumani and Mwea (Table 6). However, the interaction between tillage°×°mulch°×°variety significantly ($P = 0.03$) affected the harvest index in Katumani but not in Mwea (Table 6). Variety KS20 under zero tillage with no mulch recorded a higher harvest index (35%) and least in conventional tillage mulched with 3 t·ha^{-1} plant residues (Table 6). Generally, variety KS20 recorded a higher harvest index compared to N26 (Table 6).

Table 5: Number of pods per plant, number of seeds per pod, and thousand (1000) seed weight under contrasting tillage method and mulch in Katumani and Mwea.

Treatments + interactions	Katumani			Mwea		
	NPP	NSP	TSW	NPP	NSP	TSW
Conventional tillage	41c	13a	55.54c	38c	13a	64.00a
Furrow-ridge	61a	13a	71.35a	44a	13 a	69.00a
Zero tillage	48b	13a	60.32b	40b	13 a	64.92a
LSD	1.51	0.87	1.91	1.89	1.28	5.06
P value	<.001	0.678	<.001	0.002	0.864	0.102
Mulch						
0 $t{\cdot}ha^{-1}$	46b	13a	60.48b	37b	13a	63.11b
3 $t{\cdot}ha^{-1}$	54a	13a	64.33a	44a	13a	68.33a
LSD	2.04	0.19	1.75	1.56	0.24	2.39
P value	<.001	1.00	0.002	<.001	0.06	0.003
Variety						
KS20	47b	13b	63.89a	36b	13b	68.83a
N26	53a	14a	60.92b	45a	14a	63.11b
LSD	2.01	0.17	0.80	1.33	0.24	1.28
P value	<.001	<.001	<.001	<.001	<.001	<.001
Interactions						
Tillage°× mulch	0.55	0.3	0.86	0.54	0.73	1.00
Tillage°× variety	0.03	0.62	0.74	0.43	0.22	0.89
Mulch°× variety	0.25	1.00	0.19	0.01	0.34	0.78
Tillage°× mulch°× variety	0.54	0.26	0.83	0.38	0.78	0.05

LSD is the least significant difference; NPP = number of pods per plant, NSP = number of seeds per pod, TSW = thousand seed weight and means followed by the same letter are not significantly different at $P \leq 0.05$.

Table 6: Shoot biomass, grain yield, and harvest index under contrasting tillage methods and mulch in Katumani and Mwea.

Treatments + interactions	BH ($t\ ha^{-1}$)	Y ($t\ ha^{-1}$)	HI (%)	BH ($t\ ha^{-1}$)	Y ($t\ ha^{-1}$)	HI (%)
Conventional tillage	3.13b	0.93c	30	3.0b	0.91b	31
Furrow-ridge	3.63a	1.09a	30	3.5a	0.96a	27
Zero tillage	3.22b	1.01b	31	3.0b	0.92ab	31
LSD	0.19	0.03	0.02	0.17	0.05	0.03
P value	0.004	<.001	0.125	0.002	0.044	0.04
Mulch						
0 $t{\cdot}ha^{-1}$	3.1b	0.94b	31	2.9b	0.85b	30
3 $t{\cdot}ha^{-1}$	3.6a	1.08a	30	3.5a	1.01a	29
LSD	0.29	0.03	0.03	0.21	0.05	0.03
P value	0.005	<.001	0.453	<.001	<.001	0.77
Variety						
KS20	3.1b	0.9b	31	3.0b	0.91b	30
N26	3.6a	1.1a	30	3.4a	1.01a	30
LSD	0.12	0.02	0.01	0.13	0.05	0.02
P value	<.001	<.001	0.371	<.001	<.001	0.51
P values for interactions						
Tillage°×°mulch	0.01	0.19	0.43	0.31	0.57	0.46
Tillage°×°variety	0.38	0.02	0.08	0.83	0.23	0.28
Mulch°×°variety	0.09	0.01	0.24	0.19	0.38	0.93
Tillage°×°mulch°×°variety	0.05	0.04	0.03	0.21	0.56	0.79

LSD is the least significant difference; BH = biomass at harvest, Y = yield, HI = harvest index, and means followed by same letter are not significantly different at $P \leq 0.05$.

4. Discussions

4.1. Effect of Tillage Methods and Mulch Application on Growth Parameters. There were significant effects of tillage methods and mulch application on the plant height and number of branches. Crop under furrow-ridge recorded higher plant heights, followed by those under zero tillage and finally those under conventional tillage. The higher plant height recorded under furrow-ridge compared to conventional and zero tillage could be attributed to the decreased soil bulk density and increased soil proliferation of roots for uptake of water and nutrients. These findings have been supported by Aikins and Afuakwa [21] who reported high plants in deeply tilled (disc plowed) plots. Loosening the soils through improved tillage and the creation of furrows and ridges creates an ideal seedbed condition which influences the growth of crops resulting in increased plant heights [22]. Consistent results of significantly high plant heights in tilled treatment than those under no-till were also reported by Diaz-zorita [23].

A significantly high number of branches recorded in furrow-ridge and a low number of branches in conventional and zero tillage have been attributed to the variation in plant growth because of water and nutrient availability created by furrow-ridge and the addition of 3 t·ha^{-1} of mulch. These results agree with the findings of [24] who reported significantly higher plant heights under the furrow-ridge system than in minimum tillage. Further studies by Jiotode et al. [25] have supported these findings.

Additionally, mulching had a significant role in influencing the number of branches in the two study sites. Plants under plots mulched with 3 t·ha^{-1} of plant residue recorded a greater number of branches than those in plots without mulch. The increase in the number of branches could be due to moisture conserved in the soil by the mulch [26].

The results showed that tillage and mulch application significantly affected root biomass at flowering and harvest. Higher root biomass recorded under furrow-ridge could be due to the ideal soil conditions such as increased soil moisture retention, aeration, and easy root penetration and expansion. Contradicting results to these findings have been reported by Sidiras et al. [27] who reported higher root biomass in zero tillage compared to minimum and conventional tillage. Similar findings have been reported by Khursid et al. [22] who recorded greater root of a vegetable pea because of mulching.

4.2. Effect of Tillage and Mulch Application on Yield and Yield Components. Tillage and mulch application significantly affected the number of pods per plant, seeds per pod, and thousand seed weight. The number of pods, seeds per pod, and thousand seed weights recorded under furrow-ridge were higher compared to conventional and zero tillage. The addition of 3 t·ha-1 of mulch also significantly increased the number of pods per plant as well as thousand seed weight (Table 6). The increased number of pods per plant recorded in furrow- ridge and mulched plots could be attributed to more moisture retention. Polthanee and Wannapat [28] also reported that mulch application significantly increased the number of pods per plant and a greater number of seeds per pod.

The higher number of pods in N26 could be attributed to the genetic divergence which has been revealed in the high number of branches compared to KS20. These findings were supported by Khaemba et al., [29].

The difference in the number of seeds per pod could be attributed to the inheritance of the genetic difference in the varieties. In their study, Khaemba et al. [29] concluded that the number of seeds per plant is solely influenced by the genotypic characteristics of the crop. Similar findings have been reported by Mulika et al. [30] who recorded a varied number of seeds per plant with three different green gram varieties.

High seed weight recorded under furrow-ridge could be due to soil softness, deeper penetration of roots in the soil, and conservation of soil moisture which is the prerequisite for optimal crop productivity. These study findings agree with Khurshid et al. [22] who found that tillage and mulch had significant effects on the seed weight of maize. Similarly, Khan et al. [31] also reported an increase in thousand-grain weight under different tillage practices. Furthermore, findings by Teame et al. [32] indicated that 1000 seed weight varied significantly with mulching. The varietal significant difference in 1000 grain seed weight of the two green gram varieties could be attributed to the varietal genetic difference and composition. Variety KS20 possessed bigger seed grains compared to N26 and hence its higher grain weight. These findings agree with those of Mulika et al. [30] who reported different grain weights in three green gram varieties.

Tillage methods and mulch application significantly affected the grain yield and biomass of green gram. There were higher grain and biomass yields recorded in furrow-ridge compared to conventional and zero tillage. Similarly, the addition of 3 t·ha^{-1} plant residues played a significant role in increasing the grain and biomass yield.

The increase in green gram yields under furrow-ridge could be attributed to the increased water retention capacity and hence its availability for crop uptake. These findings agree with those of Miriti et al. [37] who attributed high yields to tied ridges. Furthermore, Huang et al. [38] reported significant variation in yield due to tillage and mulch.

There was a high grain yield reported in mulched plots compared to plots without mulch. Furrow-ridge mulched with 3 t·ha^{-1} plant residues recorded the highest grain yield, and the lowest yield was recorded in conventional tillage with no mulch. The increase in grain yield under mulched plots could be attributed to soil moisture conserved and increased infiltration provided by the mulch. This finding agrees with those of Chakraborty et al. [39]and Ogban et al. (2008) who reported increased yield in wheat and cowpea, respectively, with the application of organic mulch. Furthermore, Ndiso et al. [37] also reported that organic mulch increased soil moisture content, growth, and yield of maize plants.

The significant difference in yield recorded in variety N26 compared to KS20 could be attributed to the genetic variations which may include the number of branches, number of pods per plant, and the number of seeds per pod. The result agrees with those of Khaemba et al. [29] who reported a significant difference in grain yield with different green gram varieties. Similar findings have been reported by Mulika et al. [30].

The high shoot biomass recorded under furrow-ridge could be attributed to the increased moisture retention that enhances water and nutrient uptake leading to better translocation of nutrients which might have resulted in maximum accumulation of dry matter. The findings agree with those of Khaemba et al. [29] who reported a significant effect of tillage methods on total above-ground biomass in different experimental sites. The findings conform to those of Iqbal et al. [38] and Parlawar et al. [24] who reported an increase in biomass with different tillage methods.

Varietal difference played a key role in biomass variation, with variety N26 recorded more biomass compared to KS20. This could be attributed to soil moisture and the genetic ability of different varieties to grow and develop which could have caused the differences in biomass accumulation. Early maturing varieties tend to yield low dry matter and grain yield compared to late-maturing varieties. This is in conformity with a study conducted by Kitonyo et al. [39] who reported that early maturing crop varieties accumulate less shoot biomass compared to the late maturing ones. The article [30] also reported that growth parameters, like plant height and shoot biomass, varied significantly with variety. Furthermore, Karimi et al. [40] also reported varied biomass accumulation due to varietal differences. Chandra et al. [41] reported a high harvest index in early maturing pea varieties (*Pisum sativum*) compared to late maturing ones.

5. Conclusion and Recommendation

Crop production in arid and semiarid areas has always been affected by water scarcity and poor soil fertility. These constraints have led to a decline in food production, rendering communities to poverty and food insecurity. With the recurrent changes in weather due to climate change, researchers have resolved in working toward technologies, innovation, and tillage management practices also called climate-smart agriculture (CSA) that will ensure the increased amount of water retention in the soil and improve the soil fertility content.

This study found that furrow-ridge mulched with $3\,\mathrm{t{\cdot}ha^{-1}}$ plant residue increased green gram growth and yields under arid and semiarid conditions. Therefore, the combination of furrow-ridge and $3\,\mathrm{t{\cdot}ha^{-1}}$ plant residue can be recommended for increased green gram yield in a water-stressed environment [42–48].

Data Availability

Data analyzed were collected from two experimental sites in Kenya: Katumani and Mwea. Data for the results discussed are available and could be provided if the need arises.

Disclosure

All the authors of this manuscript are affiliated with the University of Nairobi; the main author is a student supervised by Dr. Josiah, Dr. Kitonyo, and Prof. George who are all lecturers at the University of Nairobi. This work is part of the university's partial fulfillment for the award of Master of Science.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

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