Original Research Article

Double row improved system productivity of green gram-sorghum intercrop in dryland conditions of Kenya

ABSTRACT

Small scale farmers in dryland areas normally grow green gram (*Vigna radiata* L.) under sole crop system. However, studies done on intercropping systems have established that plant arrangement patterns affect crop growth and yield of the companion crops. To advance a better understanding of the effect of crop arrangement in green gram varieties intercropped with sorghum (*Sorghum bicolor* L.), two field experiments were conducted during the 2022 short rains season in dryland areas of Kenya. This study was explored under two intercrop arrangement patterns (Single row; alternate rows of sorghum and green gram; double row, double alternate rows of sorghum and green gram) as well as checks of both sole crops. Four green gram varieties such as KS20, N26, Biashara, and Karembo were intercropped with sorghum variety Seredo. Treatments were placed in a randomized complete block design with a split-plot arrangement where crop arrangement system formed the main plots while the green gram variety assumed the subplots and replicated three times. Data were subjected to analysis of variance using R software and treatment means separated by Fisher's least significant difference at 5% probability. The results of the present study show that sole green gram recorded the highest yield of 0.9 t ha^{-1} the same way sole sorghum recorded the highest yield of 2.7 t ha^{-1}. Variety N26 recorded highest yield of 1.0 t ha^{-1} despite Biashara variety recording higher seed weight than N26 by 29%. Double row recorded a higher area time equivalent ratio of 1.5, and benefit-cost ratio of 4.3. In conclusion, double row of variety N26 was found to be more efficient and profitable for adoption in southeastern Kenya. However, future research could be done to evaluate other green gram variety not used in the current study and focus on the optimum spacing that can reduce intercropping competition and improve yield performance.

Keywords: Double row, Single row, Sole crop, Area time equivalent ratio, Benefit-cost ratio

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1. INTRODUCTION

The current global challenge is to produce food for an increased human population, which is estimated to grow beyond 9.8 billion by 2050 (Lamessa et al., 2015; Arshad et al., 2020). Feeding such a population with reduced land sizes requires climate-smart technologies that are sustainable such as intercropping (Layek et al., 2018). Intercropping is the practice of growing two or more crops simultaneously on the same piece of land (Ewansiha et al., 2018). Intercropping normally mitigates the risk of crop failure, safeguards household food security, dietary diversity and incomes (Mugo et al., 2020; Dang et al., 2020). However, dryland agriculture has been threatened by frequent droughts, high temperatures, and low soil fertility that has led to reduced crop productivity (Fang et al., 2024; Harisha et al., 2024). In southeastern Kenya, drought resistant crops such as sorghum (*Sorghum bicolor* L.) and green gram (*Vigna radiata* L.) can be intercropped to increase system productivity (Mugo et al., 2020; Okeyo et al., 2020).

Cereal-legume intercropping provides the opportunity to mitigate the risk of crop failure and safeguards household food security and incomes (Bremer et al., 2024; Mugo et al., 2020). Evidence shows that intercropping often increases crop productivity (Bugilla et al., 2023; Simon-Miquel et al., 2024). However, in some instances yield reduction in intercrop systems is reported in comparison with sole crop systems (Bremer et al., 2024). Despite the numerous benefits of intercropping, green gram-sorghum intercropping in dryland areas has been largely underexploited leading to the use of sole production systems (Mugo et al., 2020; Okeyo et al., 2020). To maximize the yield of companion crops, intercrop systems should be considered to maximize resources use through proper crop arrangement patterns and varieties (Tang et al., 2020; Wang et al., 2020).

The design of intercropping systems is influenced by variety, plant arrangements, plant population, nutrient requirements, and maturity dates (Telkar et al., 2018). Farmers in southeastern Kenya, normally intercrop green gram with sorghum in alternating single row, two crops grown in the same row or in the same holes (Wambua et al., 2017). Generally, green grams are shaded by sorghum during their growing period and overcomes this by modifying the intercepted radiation leading to increase plant height and reduce the number of branches (Hussain et al., 2020; Qin et al., 2021). Green gram varieties that are tolerant to shading tend to have high general system productivity (Ewansiha et al., 2018). Competition for resources in intercropping can be reduced by choosing a suitable crop arrangement and growing the right variety of green gram that matures earlier than the sorghum (Baker et al., 2021; Zhang et al., 2021).

Despite the release of high-yielding green gram varieties, farmers in dry land areas of Kenya obtain green gram yield of about 0.5 t ha^{-1}, yet there is a yield potential of 3.0 t ha^{-1} (Yumbya et al., 2024; Muchomba et al., 2023). Nevertheless, this yield gap could be due to poor crop arrangement patterns, pests and diseases and is expected to deteriorate due to low and poorly distributed rainfall brought by climate change (Hakim et al., 2022; Liu et al., 2018). However, the development of early maturing varieties, high yielding and short statured green gram varieties and the availability of both local and export markets are opportunities for increasing green gram production in intercropping systems (Borah et al., 2023; Karimi et al., 2019). Most of the studies done on old and late-maturing varieties such as KS20 and N26, tried to optimize yields in sole crop production system (Mulwa et al., 2023; Muriithi, 2020). However, the new short statured green gram varieties such as Biashara and Karembo could lead to many weeds to grow due to high radiation penetration. It has been reported that taller varieties with bush canopy such as N26 requires a wider spacing offering a higher competition for radiation capture (Sun et al., 2019). Canopy with bigger branches suppresses weeds and helps the soil to retain moisture which are important characteristics in dryland areas (Yumbya et al., 2024; Gaudio et al., 2019).

Studies done under a sole cropping system produced low yields leading to low adoption of green gram intercropping systems (Temeche et al., 2022). Therefore, selection of green gram varieties for intercropping would depend on crop arrangement x variety interactions that would contribute to high yield in green gram-sorghum intercrop (Gebeyehu et al., 2006). However, in dryland areas of Kenya, the information on the effect of variety and crop arrangement systems on sorghum and green gram intercropping is scanty. This study investigated the effect of row arrangements of green gram varieties intercropped with sorghum. It was hypothesized that: (i) crop variety significantly affects interactions between companion crops in the intercrop system; (ii) crop arrangement pattern influences intercropping intimacy on growth and yield of green gram and sorghum in southeastern Kenya.

2. MATERIALS AND METHODS

2.1. Experiment sites

Field experiments were conducted in Katangi and Mwala, both in Machakos County of southeastern Kenya during the 2022 short rains season. Katangi site is located at 1º40´13´´S, 37º68´18´´E and 1051 m altitude while Mwala is at 1º21´29´´S, 37º27´41´´E and 1252 m elevation. Katangi site falls in the drier LM-4 zone while Mwala site is in the low midland agroclimatic zone (LM-3). The sites have bimodal rainy seasons per annum, which are distributed in a long rains season from March to May and a short rains season from October to December which is more reliable. The long-term mean annual rainfall in both sites is 600-700 mm and the air temperature range is 17-35 ºC (Manzi et al., 2023; Ndolo, 2019). Soils in the sites are feral chromic luvisols which are well-drained to vertisols with pH of 6 (Yumbya et al., 2024).

2.2 Treatments

Treatments constituted three crop arrangement systems and four green gram varieties. Three crop arrangement systems were single alternate rows of green gram and sorghum (single row), double alternate rows of green gram and sorghum (double row), and checks of both sole green gram and sole sorghum. The four green gram varieties were two old varieties (KS20 and N26) and two new varieties (Biashara and Karembo) which were released in 2017 (Karimi et al., 2019). These varieties are resistant to powdery mildew, mature early, tolerate aphids, and high-yielding (Yumbya et al., 2024; Karimi et al., 2019). Sorghum variety Seredo is able to survive severe conditions, tolerate birds, matures early, high yielding, and is widely grown in southeastern Kenya (Njagi et al., 2019; Moi, 2021).

2.3. Experiment design and management

The experiment was laid out in a randomized complete block design with a split-plot arrangement which was replicated three times. Crop arrangement system assumed the main plots while the subplots were allocated to the green gram variety. Land was ploughed before sowing to a fine tilth and levelled with a rake. Plots of length 11.5 m and width of 6 m were separated by 0.5 m alleys left between the treatment plots. In the single alternate rows, the spacing between sorghum and green gram rows was 0.3 m. The intra-row spacing of sorghum plants was 0.2 m, while that of two adjacent green gram plants was 0.15 m. For double row, the spacing between sorghum and green gram rows was 0.90 m, and the intra-row spacing of sorghum plants was 0.20 m and green gram plants was 0.15 m. In the sole crop plots, green gram within row spacing was 0.5 m and between row spacing was 0.15 m while sorghum was sown 0.6 m between rows and 0.2 m between plants. The sorghum and green gram seeds were sown on the same day, one week before the onset of the 2022 short rains.

The inorganic fertilizers (N: P_2O_5: K_2O) and well-decomposed organic manure were applied as per the crop requirements after the initial soil analysis. Treatments in Katangi plots received basal dose of 57.5 kg N ha^{-1} and 57.5 kg P_2O_5 ha^{-1} while Mwala received 20 kg N ha^{-1}, 11 kg P_2O_5 ha^{-1} and 16 kg K_2O ha^{-1} of farm yard manure and 45 kg N ha^{-1} and 115 kg P_2O_5 ha^{-1} basal fertilizer while. Sorghum was top dressed with 39 kg N ha^{-1} as a split application at stem elongation and anthesis stages in both sites. Manual hand weeding was done periodically to keep the field free from weeds. Crops were regularly sprayed with pesticides, particularly against fall army worm (*Spodoptera frugiperda*) in sorghum and sucking insect pests in green gram while blight and powdery mildew in green gram was controlled by copper oxychloride fungicide.

2.4 Data collection

2.4.1 Rainfall data and soil sampling

Rainfall data (mm) was obtained from meteorological stations located near the experiment sites after every rainy event during the crop growing period. The initial soil fertility analysis before the crop establishment was done by sampling soil at 0-30 cm depth and analyzed by measuring soil pH using a pH meter in a soil-suspension deionized water solution with the ratio = 1:2.5, and organic carbon using the Walkley and Black wet oxidation method (Walkley and Black*.,* 1993) while total nitrogen was analysed by the Kjeldahl acid digestion method (Motsara and Roy*,* 2008). Olsens' method was used to measure available soil phosphorus (Olsen et al*.,* 1954) while potassium was measured using a flame photometer (Okalebo*,* 2002).

2.4.2 Green gram phenology, crop growth rate and yield attributes

Weekly phenological observations on green gram were monitored from 50% branching to flowering half way. The crop growth rate (CGR) was calculated as the rate of biomass accumulation per unit area per unit time. Five plants in the middle rows per plot were gently uprooted at various crop stages, then sun-dried to constant dry weight. CGR was determined at various stages such as branching to flowering (B-F), branching to podding (B-P), branching to physiological maturity (B-M), flowering to podding (F-P), and flowering to physiological maturity (F-M). At maturity, samples from net plot were harvested, threshed, winnowed, and grains dried for at least a week to about 12.5% water content. The yield attributes determined were pod length, 1000-seeds weight and total grain yield (t ha^{-1}) at physiological maturity.

CGR was calculated according to Bybee-Finley and Ryan (2018) as shown in Equation 1.

$$CGR = \frac{\text{Biomass } t_2 - \text{Biomass } t_1}{t_2 - t_1} \quad \text{.......... Equation 1}$$

t_2 is flowering, t_1 is stem elongation and t_2-t_1 is the number of days between the two stages.

2.4.3 Sorghum phenology, tillers and grain yield

Sorghum phenology data was collected on the duration from sowing to 50% stem elongation and anthesis halfway. During the critical crop growth period, the number of emerged fertile tillers were counted per plot at tillering and 90% physiological maturity and expressed per unit area. Mature sorghum heads were harvested manually and yield components determined from net plots. Seeds were removed from the heads, total grain yield (t ha^{-1}) obtained after drying the grains to about 12.5% water.

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2.5 Area time equivalent ratio and benefit cost ratio

2.5.1 Area time equivalent ratio

Area time equivalent ratio (ATER) offers a greater reliable respect of the harvest intercropping advantage as opposed to sole crops as it compares the time taken by component crops in an intercrop system. ATER according to Telkar *et al.,* (2018) is calculated as shown in Equation 2.

$$\text{ATER} = \text{LER x } \frac{\text{Dc}}{\text{Dt}} \quad \text{Equation 2}$$

Where Dc is the time taken by the green gram while Dt is the time taken by the sorghum crop.

2.5.2 Benefit-cost ratio

Benefit-cost ratio (BCR) is used to evaluate the technology that will be adopted by farmers by comparing the cost of production with production returns, as opposed to the monetary advantage index). MAI ~~which~~ combines intercrop profits without separating returns from the two crops. BCR according to Ofuyo et al. (2020) is calculated as shown in Equation 3.

$$\text{BCR} = \frac{\text{Gross monetary returns}}{\text{Total cost of production}} \quad \text{Equation 3}$$

2.6 Data analysis

Before statistical analyses, Shapiro-Wilk test was used to check for data normality and homogeneity. All measured data met normality test, hence were subjected to R software version 4.3.3.0 using two way analysis of variance to establish significant differences (LSD) at P ≤ 0.05 between treatment effects and their interactions. All data were expressed as means ± standard error of mean (SEM). The goodness of fit was assessed by calculating R^2.

3. RESULTS

3.1 Rainfall data during the 2022 short rains

In 2022 short rains, Mwala recorded cumulative rainfall of 227 mm while Katangi received 190.8 mm (Figure 1). This amount of rainfall was similar to the estimated long-term mean for the short rains season in each site. Although, the amount of rainfall received was below the expected critical 250 mm of water required to optimize green gram (Mugo et al., 2020) and 300 mm for sorghum productivity (Moi, 2021).

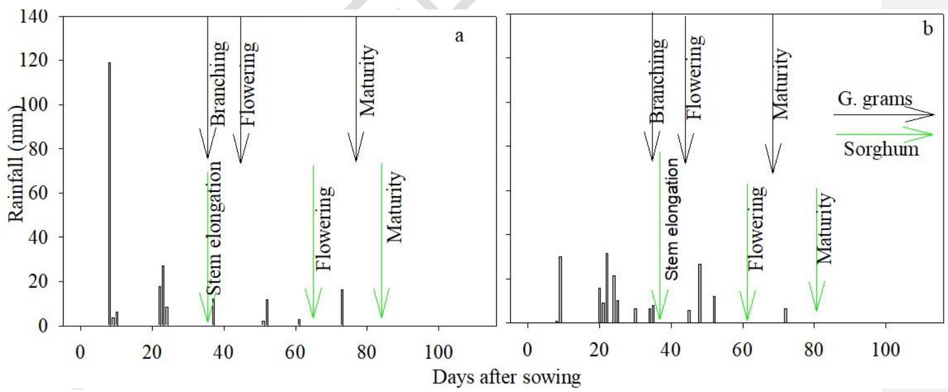

Figure 1. Rainfall (mm) during sorghum and green gram growing period at Mwala (a) and Katangi (b) during the 2022 short rains season

Soils sampled were of low fertility and moderately acidic in Katangi ranging from 5.7-7.2. Total nitrogen was 0.8-1.5 g kg^{-1} and phosphorus was13-26 mg kg^{-1} which were low hence were supplied through the application of inorganic fertilizer. The

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3.2. Green gram grain yield and grain attributes

Results in Table 1 shows that there were significant interactions between variety and crop arrangement where variety N26 produced the highest mean yield of 1.0 t ha^{-1} while the sole crop recorded the highest mean yield (0.91 t ha^{-1}) compared with double row (0.75 t ha^{-1}) and single row (0.62 t ha^{-1}). The mean values of 1000 seed weight ranged from 61.0 g for the N26 variety to 85.4 g for the Biashara variety (Table 1). Similarly, crop arrangement system was significantly ($P < 0.001$) affected by 1000 seed weight, with the highest mean value documented was 75.8 g in the sole crop system while single row recorded the least of 65.3 g (Table1).

Table 1. Grain yield (t ha^{-1}) and 1000 seed weight (g) of four green gram varieties grown as sole crops and intercropped with sorghum in single and double alternate rows in Mwala and Katangi during 2022 short rains season

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Site and Variety	Grain yield (t ha^{-1})				1000-seed weight (g)			
	Sole crop	Single row	Double row	Mean	Sole crop	Single row	Double row	Mean
Mwala								
N26	1.30 ± 0.01a	0.89 ± 0.01e	1.08 ± 0.01c	1.09 ± 0.01a	67.3 ± 0.6f	57.8 ± 0.7h	61.4 ± 1.1g	62.2 ± 0.4d
Biashara	1.12 ± 0.02b	0.79 ± 0.01f	0.95 ± 0.02d	0.95 ± 0.02b	84.5 ± 0.8a	77.4 ± 0.4c	80.4 ± 0.9b	80.8 ± 0.9a
Karembo	0.76 ± 0.02e	0.53 ± 0.01j	0.65 ± 0.02h	0.65 ± 0.02c	79.2 ± 0.4b	70.2 ± 0.8d	78.2 ± 0.6c	75.9 ± 0.6b
KS20	0.60 ± 0.01i	0.36 ± 0.01l	0.49 ± 0.02k	0.48 ± 0.02d	72.2 ± 0.4e	62.2 ± 0.9g	67.4 ± 0.8f	67.3 ± 0.8c
Mean	0.95 ± 0.02A	0.64 ± 0.01C	0.79 ± 0.02B		75.8 ± 0.6A	66.9 ± 0.7C	3.7 ± 0.9B	
Katangi								
N26	1.20 ± 0.02a	0.82 ± 0.02d	0.95 ± 0.03b	0.99 ± 0.02a	64.5 ± 0.3e	57.2± 0.5g	61.4 ± 0.4f	61.0 ± 0.8d
Biashara	0.89 ± 0.02c	0.66 ± 0.01g	0.80 ± 0.02e	0.78 ± 0.02b	85.4 ± 0.6a	70.6 ± 0.4d	79.5 ± 0.3b	78.5 ± 0.9a
Karembo	0.74 ± 0.01f	0.52 ± 0.01i	0.62 ± 0.02h	0.63 ± 0.01c	79.5 ± 0.8b	65.8 ± 0.7e	73.9 ± 0.6c	73.1 ± 0.6b
KS20	0.62 ± 0.01h	0.35 ± 0.03k	0.45 ± 0.02j	0.47 ± 0.02d	73.4 ± 1.1c	60.9 ± 0.6f	65.4 ± 0.4e	66.6 ± 0.5c
Mean	0.86 ± 0.02A	0.59 ± 0.02C	0.71 ± 0.02B		75.7 ± 0.7A	63.6 ± 0.6C	70.1 ± 0.4B	

Values are means ± standard error of mean. Means followed by the same letter at not significantly different at 5% probability level.

3.3 Green gram phenology and crop growth rate

Table 2 results reveal that the four green gram varieties differed significantly (P < 0.001) in phenology during branching and flowering where KS20 flowered 15 days earlier than N26. Crop arrangement system x variety interaction had a significant effect on the duration of green gram from branching up to flowering in both sites where double row took 9 more days than the sole crop (Table 2).

Table 2. Days to 50% branching and 50% flowering of four green gram varieties grown as sole crops and intercropped with sorghum in single and double alternate rows in Mwala and Katangi during 2022 short rains season

Site and Variety	Branching				Flowering			
	Sole crop	Single row	Double row	Mean	Sole crop	Single row	Double row	Mean
Mwala								
N26	38.7 ± 0.4d	39.7 ± 0.8c	46.3 ± 0.4a	62.2 ± 0.5d	48.0 ± 0.6e	51.7 ± 0.7c	58.0 ± 1.1a	52.6 ± 0.4a
Biashara	32.3 ± 0.8h	36.7 ± 0.9e	42.3 ± 0.9b	80.8 ± 0.8a	44.7 ± 0.8f	49.3 ± 0.4d	52.7 ± 0.9b	48.9 ± 0.9b
Karembo	29.3 ± 0.7i	34.3 ± 0.6f	36.7 ± 0.6e	75.9 ± 0.7b	38.0 ± 0.4i	42.3 ± 0.8g	45.0 ± 0.6f	41.8 ± 0.6c
KS20	22.0 ± 0.5k	25.0 ± 0.4j	33.0 ± 0.4g	67.3 ± 0.4c	32.0 ± 0.4k	35.0 ± 0.9j	40.0 ± 0.8h	35.7 ± 0.8d
Mean	30.6 ± 0.6C	33.9 ± 0.7B	39.6 ± 0.6A		40.7 ± 0.6C	44.6 ± 0.7B	48.9 ± 0.9A	
Katangi								
N26	33.3 ± 0.4e	40.0 ± 0.7b	45.0 ± 0.03b	39.4 ± 0.02a	44.0 ± 0.3d	51.0± 0.5b	55.0 ± 0.4a	50.0 ± 0.8a
Biashara	32.3 ± 0.4f	36.7 ± 0.9c	40.3 ± 0.02e	36.4 ± 0.02b	42.7 ± 0.6e	46.0 ± 0.4c	51.3 ± 0.3b	46.7 ± 0.9b
Karembo	29.7 ± 0.8g	32.3 ± 0.6f	35.0 ± 0.02h	32.3 ± 0.01c	39.7 ± 0.8f	42.7 ± 0.7e	46.0 ± 0.6c	42.8 ± 0.6c
KS20	27.3 ± 0.5h	29.7 ± 0.5g	32.3 ± 0.02j	29.8 ± 0.02d	33.0 ± 1.1h	36.3 ± 0.6g	40.0 ± 0.4f	36.4 ± 0.5d
Mean	30.7 ± 0.5C	34.7 ± 0.7B	38.2 ± 0.02A		39.9 ± 0.7C	44.0 ± 0.6B	48.1 ± 0.4A	

Values are means ± standard error of mean. Means followed by the same letter at not significantly different at 5% probability level.

There was a strong relationship between crop growth rate (CGR) and yield as presented in Figures 2a to 2e. CGR between branching to maturity was positively ($R^2 \geq 0.78$) associated with yield. Similarly positive strong associations ($R^2 \geq 0.71$) were measured on CGR between flowering to maturity and yield. The yield hectare^{-1} is a function of crop growth rate between branching to flowering which is a critical window of yield determination fitted by equation $y = 0.19x + 0.15$ ($R^2 = 0.47$) in Mwala. The grain yield increased linearly at the rate of 0.19 t ha^{-1} with every incremental unit of 1 g m^{-2} day^{-1} in Mwala while grain yield in Katangi increased linearly at much higher rate of 0.21 t ha^{-1}.

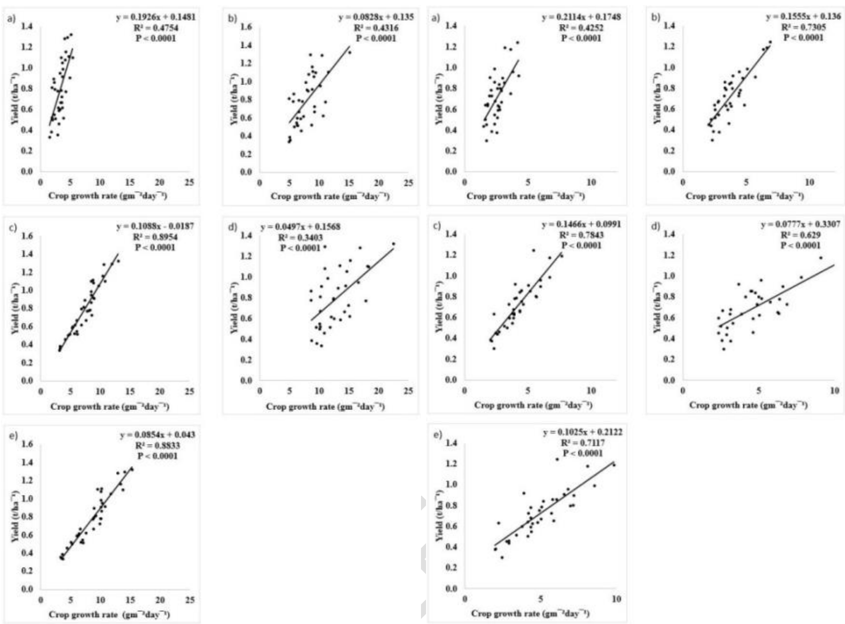

Figure 2. Relationship between green gram yield (t ha^{-1}) on crop growth rate (CGR) at branching to flowering a), branching to podding b), branching to maturity c), flowering to podding d), flowering to physiological maturity e) in Mwala during 2022 short rains season on the left hand side and relationship between green gram yield (t ha^{-1}) and crop growth rate (CGR) at branching to flowering a), branching to podding b), branching to maturity c), flowering to podding d), flowering to physiological maturity e) in Katangi during 2022 short rains season on the right hand side

3.4. Sorghum grain yield and yield attributes

The results in Table 3 indicate that crop arrangement influenced sorghum grain yield where the sole crop recorded the highest yield (2.2 t ha^{-1}), while in the single row the yield was reduced by 35.8%. The sole crop arrangement system registered the highest seed weight for 1000 sorghum seeds at 16.8 g. The panicle length was affected by crop arrangement system in which intercropping arrangement reduced panicle length in the double row by 3.0 cm and in single row by 6.2 cm. There was also a significant variation among the crop arrangement system where sole crop registered the highest number of fertile tillers m^{-2} (4) at the anthesis followed by double row and the least was scored by single row.

Table 3. Grain yield (t ha^{-1}), 1000-seed weight (g), panicle length (cm), number of days to stem elongation, number of days to anthesis and number of fertile tillers m^{-2} of sorghum grown as sole crop, single and double alternate rows in Mwala and Katangi during 2022 short rains season

Site and crop arrangement	Grain yield (t ha^{-1})	1000 seed weight (g)	Panicle length (cm)	No of days to stem elongation	No. of days to anthesis	Fertile tillers m^{-2}
Mwala						
Sole	3.2 ± 0.03a	18.0 ± 0.6 a	23.0 ± 0.8a	28.3 ± 0.6c	57.6 ± 0.6c	4.7 ± 0.1a
Single	2.1 ± 0.04c	15.2 ± 0.5b	17.6 ± 0.6c	32.3 ± 0.8b	63.8 ± 0.4b	1.7 ± 0.2b
Double	2.7 ± 0.05b	16.3 ± 0.8b	20.5 ± 0.4b	36.3 ± 1.1a	68.8 ± 0.5a	2.0 ± 0.4b
Mean	2.7 ± 0.04	16.5 ± 0.6b	20.4 ± 0.6	32.3 ± 0.8	63.4 ± 0.5	2.8 ± 0.2
Katangi						
Sole	2.1 ± 0.03a	15.6 ± 0.8 a	22.1 ± 0.8a	32.3 ± 0.8c	56.0 ± 0.6c	3.6 ± 0.1a
Single	1.3 ± 0.03c	11.2 ± 0.6 c	15.1 ± 0.7c	35.0 ± 0.6b	59.3 ± 0.4b	1.0 ± 0.2c
Double	1.7 ± 0.04b	13.8 ± 0.5b	18.6 ± 0.6b	37.9 ± 0.4a	63.3 ± 0.3a	2.3 ± 0.3b
Mean	1.7 ± 0.03	13.5 ± 0.6	18.6 ± 0.7	35.1 ± 0.6	59.5 ± 0.4	2.3 ± 0.2

Values are means ± standard error of mean. Means followed by the same letter at not significantly different at 5% probability level.

3.5 Sorghum phenology and tillers

Green gram-sorghum intercropping had significant effect on phenology during stem elongation and anthesis where the double row took 9 more days to flower while single row took 5 more days than the sole crop (Table 3). At maturity, the sole crop registered the highest number of fertile tillers m^{-2} (4) followed by double row (2) and the least were scored by the single row (1).

3.6 Area time equivalent ratio and benefit cost ratio

Area time equivalent ratio (ATER) values showed that, double row attained the highest ATER values of 1.5. Similarly, double row exhibited highest value of benefit cost ratio (BCR) of 4.3. Among the four green gram varieties under intercropping arrangements, variety N26 recorded the highest BCR of 4.5 and ATER of 1.44 (Table 4).

Table 4. Area time equivalent ratios and benefit cost ratio of four green gram varieties grown as sole crops and intercropped with sorghum in single and double alternate rows in Mwala and Katangi during 2022 short rains season

Site and Variety	Area time equivalent ratio			Benefit cost ratio		
	Single row	Double row	Mean	Single row	Double row	Mean
Mwala						
N26	1.37 ± 0.13b	1.58 ± 0.09a	1.48 ± 0.11ab	3.34 ± 0.12b	4.49 ± 0.14a	3.92 ± 0.13a
Biashara	1.33 ± 0.12b	1.58 ± 0.08a	1.46 ± 0.10b	2.95 ± 0.13a	4.20 ± 0.13a	3.58 ± 0.13b
Karembo	1.60 ± 0.11a	1.60 ± 0.10a	1.60 ± 0.11a	2.11 ± 0.10b	3.26 ± 0.12a	2.69 ± 0.11c
KS20	1.46 ± 0.10b	1.44 ± 0.11a	1.24 ± 0.11c	1.71 ± 0.11b	2.91 ± 0.13a	2.31 ± 0.12d
Mean	1.44 ± 0.12B	1.55 ± 0.10A	1.45 ± 0.11	2.53 ± 0.12A	3.72 ± 0.13A	3.28 ± 0.13
Katangi						
N26	1.22 ± 0.11c	1.58 ± 0.11a	1.40 ± 0.12a	4.35 ± 0.11b	5.87 ± 0.13a	5.11 ± 0.12a
Biashara	1.56 ± 0.14a	1.55 ± 0.13a	1.37 ± 0.11b	3.87 ± 0.12b	5.51 ± 0.11a	4.69 ± 0.12b
Karembo	1.53 ± 0.13a	1.44 ± 0.10b	1.29 ± 0.12c	2.83 ± 0.12b	4.33 ± 0.12a	3.58 ± 0.12c
KS20	1.40 ± 0.11b	1.23 ± 0.12c	1.10 ± 0.10d	2.34 ± 0.13b	3.89 ± 0.14a	3.12 ± 0.14d
Mean	1.43 ± 0.12A	1.45 ± 0.12A	1.29 ± 0.11	3.35 ± 0.12B	4.9 ± 0.13A	4.13 ± 0.13

Values are means ± standard error of mean. Means followed by the same letter at not significantly different at 5% probability level.

3.7 Relationship between sorghum growth traits as drivers of grain yield

Results in Table 5 presents the correlation between growth traits and sorghum yield which revealed significant positive association showing a situation where both traits increased with the same magnitude. The sorghum yield was strongly and significantly ($P \leq 0.001$) correlated with crop growth rate (0.95***), panicle length (0.94***) and seed weight (0.90***).

Table 5. Correlation coefficients between crop growth rate and yield attributes of sorghum during 2022 short rains season

Variable	Crop growth rate ($g\ m^{-2}\ day^{-1}$)	Yield ($t\ ha^{-1}$)	1000 seed weight (g)
Panicle length	0.96***	0.94***	0.96***
1000 seed weight	0.92***	0.90***	
Yield	0.95***		

*** *indicates highly significant at p<0.001*

4. DISCUSSION

Different crop arrangement patterns and green gram varieties have varied solar radiation capture which results in low or high yield attributes (Li 2021; Wu et al., 2022). In this study, intercropping, irrespective of crop arrangement reduced grain yield by 32% in green gram and 26% in sorghum compared to sole cropping. The yield reduction in intercrop systems was directly linked with decreased crop growth rate during the critical growth stages of the two crops. There were synergistic relationship between green gram, sorghum and associated crop arrangement patterns as shown by values of productivity and economic indices (Table 4).

4.1 Yield and yield components

In the drylands of Kenya, farmers select green gram varieties because of their size, taste, and yield (Masaku, 2019; Mugo et al., 2020). Variety N26 out-yielded KS20 by 0.56 t ha^{-1} and took 15 more days to flower compared with KS20. This variation in phenology between varieties could be linked to genetic differences and rainfall amounts received at different sites. KS20 which flowered and matured earlier should thus be considered as a drought-escaping variety (Masaku, 2019). The similar maturity period and yield of green gram agrees with the results of Karimi et al. (2019) and Mulwa et al. (2023). The high amount of rainfall received in Mwala resulted in better growth and more number of days to reach various stages as shown in Figure 1.

In the present study, intercropping significantly reduced grain yield, both in double row and in single row arrangement compared with sole crops which could be associated with reduced crop growth rate. These results are similar to those of Telkar *et al*. (2018) who recorded higher CGR in double row compared with single row in maize-soybean intercropping. The short crop species like KS20 normally experience negative effects due to shading by tall sorghum plants which was much higher especially under single row which had reduced spacing (Wang et al., 2020). Since sole crop was effective in increasing individual grain yields while intercropping significantly decreased green gram yield, this system could therefore be adjusted to maximize resources use efficiency and increase yield.

4.2 Sorghum phenology and tillering

Double row took significantly more days to stem elongation and flowering compared with single row and sole sorghum. This implies that double row could have provided a better environment which increased vegetation growth and increased the number of days to mature. These results resonates well with Rashid Abdur and Himayatullah (2003) and Rashid et al. (2004) who found double row intercropping arrangement took the maximum number of days to mature followed by single row. Tillers are controlled by genetic factors, environment, management practices, and their interactions (Moi, 2021). The number of fertile tillers m^{-2} varied significantly among the crop arrangement system where the sole crop produced more tillers m^{-2} compared with the intercrop system. This was probably because the sole crop received more resources. The present results agrees with report of Thapa et al. (2018).

4.3 Intercropping productivity and economic indices

The highest Area time equivalent ratio (ATER) was registered at 1.6 in Karembo under double row in Mwala and 1.57 in N26 under double row in Katangi indicating a higher complementary effect of green gram in the double row. ATER values for the double row and single row ranged between 1.0 to 1.6 which indicated up to 60% advantage with sorghum-green gram intercrop over sole crop system. Similar results were recorded by Telkar *et al*. (2018) on maize-soybean and Chaudhary et al. (2022) on wheat-chickpea intercrop. Further studies are required due to variety x environment interaction. Benefit cost ratio (BCR) was calculated using the mean market prices of seeds, fertilizers, agrochemicals, and labor in the study area. The double row of variety N26 registered the highest BCR of 5.1. This was probably due to good market prices offered for the green grams. Our findings are in agreement with Sahu (2023) on chickpeas-chandrasur intercrop and Begum et al. (2018) on sorghum/garden peas intercrop. The present results show that double row crop arrangement system with variety N26 is a better management practice that could be used to improve crop productivity and profitability to farmers in dryland areas.

5. CONCLUSION

In conclusion, that there exists significant differences in the growth characteristics and yield attributes of evaluated green gram varieties and crop arrangements. Green gram variety N26 under double row arrangement is an anticipative agronomic strategy with a greater potential ability to improve green gram productivity and farmers benefits in dryland areas of Kenya. It was established that, despite the yield decline in the intercropping system, there is potential to exploit crop arrangement patterns and variety interactions to increase yields in drylands which have low rainfall and poor soils. The key contributors identified due to their positive interrelationships with grain yield in green gram were crop growth rate between branching and harvesting while in sorghum were 1000 seed weight and panicle length. Nevertheless, these findings need to be backed up by future research across contrasting sites and focus on the optimum spacing that can reduce intercropping competition and improve yield performance.

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