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Original Research Article

Analysis of the Changes in Morphological Traits of Sorghum in Legume-Sorghum Intercropping Patterns in Western Kenya

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Abstract: Cereal-legumes intercropping is among the most effective agronomic strategies to boot biomass production, contribute to soil nitrogen through fixation which benefits soil productivity and sustainability. The main objective of this study was to analyze the changes in morphological traits of sorghum in legume-sorghum intercropping patterns. The experiment was conducted at KALRO Kibos station, Kisumu during long and short rainy 2020 seasons. The experimental design was randomized complete block design (RCBD) with eleven treatments replicated thrice. Data was collected on growth and yield parameters of sorghum, cowpea and soybean. Sorghum morphological traits measured were plant height, number of leaves and number of tillers, while yield data was measured on grain yield and yield components. In addition, data on competition indices was also determined using land equivalent ratio (LER) and area time equivalent ratio (ATER). Data collected was compiled and tabulated for statistical analysis using Microsoft excel software. Analysis of Variance (ANOVA) was carried out using R software version 4.2.2. Where means were significant, Tukey's test ad hoc method was used separate treatment means at 95% probability level. The results showed that sorghum morphological traits differed significantly ($P<0.001$) in the two seasons as influenced by intercropping. The greatest plant height was recorded in sorghum in alternate holes with soybean across the four months, while the highest plant height of 226.3 cm and 219.70 cm was recorded in seasons one and two respectively in 120 Days after planting (DAP). Similar results were recorded in sorghum number of leaves and tillers. Yield data showed that means of number of harvested heads, weight of harvested heads, and grain weight were statistically significant at $p<0.001$. Sorghum in alternate rows with soybean registered the maximum number of harvested heads: 21.33 and 19.67 seasons one and two respectively. Similar results were obtained in weight of harvested heads, where 1.93 kgs and 1.71 kgs in seasons one and two respectively were realized, and the trend remained the same in grain weight results which showed that sorghum recorded 5.34 t ha-1 and 4.68 t ha-1. Both LER and ATER mean values were significant at $p<0.001$ as influenced by intercropping patterns. The higher total LER of 1.82 and 1.73 were obtained from sorghum in alternate holes with soybean in seasons one and two respectively. Data regarding ATER of sorghum intercrops showed that ATER was significantly higher at $p<0.001$ than sole crop and the highest ATER scores of 1.86 and 1.75 in seasons one and two respectively were calculated in sorghum in alternate holes with soybean, an indicator of positive results. The study concluded that there was a positive impact of intercropping with legume on sorghum morphological traits.

Keywords: Cereal-legume intercropping, morphological traits, sorghum, cowpeas, soybeans.

INTRODUCTION

Sorghum (*Sorghum bicolor*) is an important major cereal crop grown mostly in semi-arid regions of Africa and Asia as a source of food and fodder, particularly in smallholder farming communities (Hadebe, *et al.,* 2017). In Kenya, sorghum is grown in the often drought prone marginal agricultural areas of Eastern (1385m ASL, 76 mm month^{-1}), Nyanza (1190 m ASL, 130 mm month^{-1}) and Coast Provinces (185 m ASL, 87 mm month^{-1}) (Grieser, 2006; Muui et al., 2013). Despite its importance in semi-arid area, it is still

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classified as an underutilized crop (Muui et al., 2013; Jacob et al., 2013). Furthermore, even after the area under sorghum cultivation was increased, and the various research intervention measures such as breeding for better yields and distribution of high-yielding and stress-tolerant sorghum varieties (Weltzien & Christinck, 2017), its average national yield in Kenya is still low at 0.8 tons per hectare (Bosire, 2019).

Globally soybean (*Glycine max*) and cowpea (*Vigna unguiculata*) are of commercial importance mainly for human and animal consumption. These legumes have been considered as important intercropping plants with positive effects on diversified cropping systems (da Silva *et al.*, 2020). According to Dwivedi *et al.*, (2015), the common crop combinations in cereal-legume intercropping systems are maize-cowpea, maize-soybean, maize-pigeon pea, maize-groundnuts, maize-beans, sorghum-cowpea, millet-groundnuts, and rice-pulses. According to Iqbal *et al.*, (2018) along with the spatial arrangements, the choice of component crops is actually the first and foremost step in the design of intercropping systems.

Intercropping is an integrated farming strategy that enhances crop productivity through complementary benefits in nutrient absorption and disease resistance (Brooker *et al.*, 2015, Li *et al.*, 2021). Legume-cereal intercropping is commonly practiced to improve nitrogen (N) nutrition by facilitating N sharing through root interactions between legumes and cereals, such as soybean and maize (Li *et al*., 2021). Furthermore, intercropping can minimize nitrate leaching in the soil profile due to the efficient absorption of different root architectures (Chai *et al.*, 2021). The introduction of legumes into intercropping systems appears to be beneficial depending on the extent to which legumes fix atmospheric nitrogen. Legumes based intercropping systems improves the absorption of macro and micronutrients from the soil along with nutrient use efficiency (NUE) (Crews and Peoples, 2004). Intercropping of sorghum and palisade grass (*Urochloa brizantha* L.) in narrow row spacing (0.90 m) yielded a better forage production than wider row spacing, owing to significantly higher NUE (Borghi *et al.*, 2013). Another key advantage associated with intercropping is its potential to increase the land productivity per unit area and the efficient utilization of farm resources (Mucheru-Muna *et al.*, 2010). Therefore, the objective of this study was to analyze the changes in morphological traits of sorghum in legume-sorghum intercropping patterns in the Western region of Kenya.

MATERIAL AND METHODS

Description of the Study Site

This experiment was carried out in KALRO Kibos station, Kisumu during the long rainy season (March through June) and short rainy seasons (November through December) of the year 2020 respectively (Odhiambo *et al.*, 2015). Kibos is located in Kajulu village of Kisumu East sub-county in Kisumu County. Geographically, Kibos lies between latitude 0°04’S; longitude 34°48’E; and altitude 1184 m above sea level (Atera, 2012), while the experimental site lied between latitude 0°04’S; longitude 34°48’E. The site has a sub-humid climate with the following long term climatic parameters: 1287 mm annual average rainfall, 5.2 mm evaporation, 26.5 MJm^{-3} radiation, 7.2 hours sunshine, 60 % mean relative humidity and 22.5 ^{0}C, mean daily temperature (Climate data, 2012). Kibos is majorly endowed with soils that are heavy black clay (Vertisols). The site lies within the Kano plain which is synonymous with the lower course of Nyando River. The plain occupies an area of approximately 430 Km^2 sandwiched between the Nandi hills and the Nyabondo plateau. The pH ranges between 6.5-6.8, with 1% organic carbon, and 1.7% organic matter (Jaetzold et al., 2005).

Field Experimental Trial

The experiment was laid out as a randomized complete block design (RCBD) design with a total of eleven experimental treatments replicated three times (Table 1). RCBD was used in this experiment because blocking reduces or eliminates experimental error that can be contributed by mediator variables.

Table 1: Experimental treatments

S1C	C	SS	S1C1	S1C2	S1C3	S1C4	S1So1	S1So2	S1So3	S1So4

Key: S1C= sole sorghum in control; C= sole cowpea; SS= sole soybean; S1C1= alternate rows with cowpea; S1C2= alternate holes with cowpea; S1C3= same hole with cowpea; S1C4= alternate with double rows of cowpea, S1So1= alternate rows with soybean, S1So2= alternate holes with soybean; S1So3= same hole with soybean; and S1So4= alternate with double rows of soybean.

The experiment consisted of 33 plots as indicated in the experimental layout (Table 2). The size of each plot measured 4m × 3m, consisting of four rows of sorghum. The sorghum spacing was 75 cm between the rows and 20 cm within the rows. Spacing of 1 m was maintained between and within the blocks.

Table 2: Field layout

Block 1	**S1C1**	**S1C2**	**S1So4**	**S1So1**	**S1So3**	**S1So2**	**S1C**	**SS**	**S1C3**	**C**	**S1C4**
Block 2	**C**	**S1So1**	**S1C1**	**S1So4**	**S1So3**	**S1So2**	**S1C4**	**S1C**	**S1C2**	**SS**	**S1C3**
Block 3	**S1So4**	**S1C3**	**S1C1**	**SS**	**S1So1**	**S1C4**	**S1C2**	**C**	**S1So3**	**S1So2**	**S1C**

Agronomic practices

Initial soil sample from the experimental field was collected using the Zigzag method (Sabbe and Marx, 1987). Soil was obtained from 10 different areas within the experimental site. The samples were obtained at 30 cm depth using soil auger. Plant residues were removed from the surface. The soil was put in a clean bucket and mixed thoroughly before taking to the laboratory.

Land preparation was done prior to the onset of the rains, before demarcation into three blocks and eleven plots in each block. Holes were dug and the recommended rate of one 50 kg bag of compound fertilizer NPK (20:20:0) per acre and top dressing was done with one bag 50 kg bag of CAN per acre as per sorghum nutrient requirement (Kisilu *et al.,* 2020). The fertilizer was thoroughly mixed with the soil. Sowing was done by hand drilling of seeds obtained from Kenya seed. The seed rate was maintained at 2 seeds per hole using KARI Mtama-1 variety. Two weeks after germination, the plants were thinned, this gave an overall, a plant population of approximately 100,000 plants per acre. Other agronomic operations were done as recommended for each crop.

Data Collection

Meteorological Measurements

During the period of the study, the temperature and rainfall measurements were taken.

Sorghum morphological traits

The morphological traits of sorghum were assessed as the growth and yield. Growth data was collected at an interval of thirty days (monthly) after planting. In each plot nine plants were selected randomly and tagged for measurement within the three internal lines. The two guard rows were not included. Further, three plants were selected per line among the best maize plants.

Plant height (cm): Measurements were taken from base of main plant to tip of panicle.

Number of basal tillers per plant of sorghum: Tiller counting was done per the tagged plants.

Number of leaves per plant: Numbers of leaves per plant were counted physically.

Sorghum yield and yield components data

Yield data was collected at the end of the experiment (one twenty days after planting). The three inner middle rows of the experimental plots were harvested to determine the final yield.

Number of harvested heads*:* All plants from the inner middle rows of each plot were harvested and number of panicles determined.

Weight of harvested heads: Heads from the inner middle rows of each plot were harvested and the weight determined in kilograms.

Grain weight: All panicles/ heads were harvested from the middle rows of each plot, threshed and grains weight determined.

Cowpea yield

Total grain yield: Pods of plants from two central rows were harvested from each plot. The pods were threshed and seeds were dried to 13% moisture content. These were weighed and each weight was converted to kilogram per hectare.

Soybean yield

Pods of plants from two central rows were harvested from each plot. The pods were threshed and seeds dried to 13% moisture content. Weights were taken and each weight was converted to kilogram per hectare.

Competition indices

Land equivalent ratio (LER)

LER is the proportionate land area required under pure stand of crop to produce the same productivity as obtained in an intercropping at the same management level. The LER was calculated as per Amanullah *et al.,* (2016).

$LER = LERp + LER_l$

$LERp = Y_{pi} / Y_{ps}$;

$LER_l = Y_{li} / Y_{ls}$.

Where LER_P and LER_l represent the partial LER of sorghum and legumes, respectively whereas Y_{pi} and Y_{li} depict the corresponding economic yield of sorghum and legume under the intercropping systems. In contrast, Y_{ps} and Y_{ls} represent the respective yields under pure stands. LER values greater than 1 are used to indicate intercropping yield advantage while those less than 1 denote a disadvantage of intercropping hence, advocating for growing the respective crops as pure stands (Machiani et al., 2018).

Area time equivalent ratio (ATER)

ATER provides a more realistic comparison of the yield advantage of intercropping over mono-cropping in terms of time taken by component crops in the intercropping systems (Hiebsch & McCollum, 1987). ATER was calculated by the formula developed by Mead & Willey (1980). It was used to compare the yield advantage of cultivating potato and legumes under intercropping to the mono-cropping by taking into consideration the time taken by the component crops under intercropping systems in the field from planting to harvesting (Doubi et al., 2016).

$$ATER = (LER_p * t_p) + (LER_l * t_l) / T$$

Where t_p and t_l is the growth period in days between planting and maturity for sorghum and legume, respectively. T is the duration of the component crop with the longest growing period. The interpretation of ATER is that ATER greater than one implies yield advantage; ATER = no effect of intercropping; ATER less than one shows yield disadvantages.

Statistical Analysis

Prior to all statistical analyses, normality was checked with Shapiro-Wilk normality tests, and homogeneity of variances was tested with Levene's tests. When normality and homogeneity assumptions were met, analyses of variance followed by Tukey's post-hoc test (Tukey honestly significant difference) were conducted to identify significant differences. The data on plant height, number of tillers, and number of leaves, LER, and ATER was subjected to two-way Analysis of Variance (ANOVA) using R software version 4.2.2.

RESULTS AND DISCUSSION

Meteorological measurements of year 2020

Rainfall amount

During the period of the study, rainfall data was generated as provided by Kisumu meteorological department as shown in Table 3. The rainfall ranged from lowest of 66.1 mm in February to highest of 349.9 mm in March.

Table 3: Rainfall measurements

Month	Jan	Feb	Mar	April	May	June	July	Aug	Sep	Oct	Nov	Dec
Rainfall (mm)	168.3	66.1	349.9	303.4	120.3	158.1	103.4	100.2	165.9	137.9	273.4	230.6

Temperature

During the period of the study, temperature data was generated as provided by Kisumu meteorological department as shown in Table 4. The highest mean temperature of 25.0 ^{0}C was recorded in January, while the lowest mean temperature of 21.95 ^{0}C was recorded in December.

Table 4: Temperature measurements

Month	Jan	Feb	Mar	April	May	June	July	Aug	Sep	Oct	Nov	Dec
Max T (^{0}C)	31.1	30.4	29.1	27.9	28.4	27.5	27.4	28.4	28.4	28.8	27.4	27.9
Min T (^{0}C)	18.9	18.2	18.6	17.7	18.9	18.0	17.9	17.8	17.5	18.7	16.7	16.0
Mean T (^{0}C)	25.0	24.3	23.9	22.8	23.7	22.8	22.7	23.1	23.0	23.8	22.05	21.95

Determining the effects of intercropping sorghum with soybean and cowpea on growth of sorghum

Plant height

Results shown in Table 5 revealed that sorghum spatial arrangements with the two legumes differed significantly at $P<0.001$ in the two seasons. In general, intercropped sorghum had greater height than sole sorghum throughout the growth period in both seasons. In both seasons, sorghum in alternate holes with soybean had significantly greater height throughout the growth period. At harvesting (120 DAP), sorghum in alternate holes with soybean recorded 65.54% and 39.05% higher plant height compared with sole sorghum in season one and two respectively. This was followed by sorghum planted either in same hole with cowpea or soybean. In season one, sole sorghum lagged behind in terms of plant height which recorded 136.7 cm.

Table 5: Effect of intercropping sorghum with soybean and cowpea on sorghum height

Plant height (cm)								
	30 DAP		60 DAP		90 DAP		120 DAP	
Treatment	Season 1	Season 2	season 1	Season 2	Season 1	Season 2	Season 1	Season 2
S1C2	14.33^{e}	24.33^{abc}	68.67^{bc}	69.00^{bc}	112.70^{d}	129.30^{cd}	187.00^{c}	162.30^{cd}
S1C	21.33^{d}	10.33^{d}	63.33^{c}	50.00^{d}	96.70^{e}	84.70^{f}	136.70^{e}	158.00^{cd}
S1C1	24.67^{cd}	21.00^{bc}	75.33^{bc}	57.33^{bcd}	120.00^{d}	112.30^{de}	160.00^{d}	145.30^{de}
S1So4	27.67^{bc}	15.00^{cd}	81.00^{bc}	65.00^{bcd}	147.70^{c}	131.00^{c}	183.30^{c}	172.70^{bc}
S1So1	27.67^{bc}	25.00^{bc}	72.67^{bc}	57.67^{bcd}	109.70^{de}	98.70^{ef}	154.00^{d}	131.70^{ef}

S1C3	28.67^{bc}	21.67^{abc}	86.00^{b}	73.33^{bc}	172.30^{b}	163.00^{b}	209.30^{b}	192.70^{b}
S1So3	30.00^{ab}	22.00^{abc}	85.67^{b}	74.00^{b}	162.70^{b}	154.00^{b}	209.00^{b}	190.70^{b}
S1C4	30.67^{ab}	12.00^{d}	77.33^{bc}	56.00^{cd}	140.00^{c}	96.30^{ef}	180.00^{c}	117.70^{f}
S1So2	34.00^{a}	28.33^{a}	127.33^{a}	112.33^{a}	191.00^{a}	184.00^{a}	226.30^{a}	219.70^{a}
P Value	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001

Within the column means followed by different letters are significantly different at p <0.001.

S1C= sole sorghum in control; S1So1= alternate rows with soybean, S1So2= alternate holes with soybean; S1So3= same hole with soybean; S1So4= alternate with double rows of soybean; S1C1= alternate rows with cowpea; S1C2= alternate holes with cowpea; S1C3= same hole with cowpea; and S1C4= alternate with double rows of cowpea: DAP= Days after planting.

Plant height is an important component which helps in the determination of growth (Muranyi & Pepo, 2013). From the study, majorly intercropping sorghum with legumes outperformed sole sorghum and this responsiveness of sorghum to intercropping is consistent with the findings of Legwaila *et al., (*2019) who reported that sorghum and cowpea intercrop showed significant difference at p<0.05 in the number of leaves, plant height, canopy spread with 50%/50% cowpeas and sorghum revealing superior absolute numbers most of the time. The height advantages of intercropping over sole cropping could probably be attributable to enhanced complementary use of growth resources (Agegnehu *et al.*, 2006) such as nitrogen and light in space and time (Jahansooz *et al.,* 2007; Liu *et al.*, 2017). Additionally, this study demonstrated that sole sorghum presented similar results as some of the spatial arrangements. For instance, sorghum in alternate holes with cowpea did not differ significantly with sole sorghum. Similar findings were reported by Undie *et al.*, (2012), Muoneke *et al.*, (2007), Alvarenga *et al.*, (1998); Yunusa (1989) and Matusso, (2014) who did not find significant differences in terms of plant height, between sole maize and intercropping with soybean.

Number of tillers

Number of tillers as captured in Table 6 shows that spatial arrangements significantly affected the number of tillers at P<0.001 in season one. The number of tillers, although significantly different, remained constant as from 60 days after seedlings emergence in all the treatments up to the end. Therefore, this period marked the end of tillering stage. Higher numbers of tillers 5.33 were found in intercropping sorghum in alternate holes with soybean 60 days after seedling emergence. This translated to 166.5% in comparison with sole sorghum. Also, all soybean spatial arrangements and sole sorghum were not significantly different from each other in 60 to 120 days after planting.

Table 6: Effect of intercropping sorghum with soybean and cowpea on number of tillers

Number of tillers								
	30 DAP		**60 DAP**		**90 DAP**		**120 DAP**	
Treatment	**Season 1**	**Season 2**	**Season 1**	**Season 2**	**Season 1**	**Season 2**	**Season 1**	**Season 2**
S1C	0.33^{c}	0.00^{b}	2.00^{b}	1.33^{a}	2.00^{b}	3.00^{a}	2.33^{b}	3.00^{a}
S1C2	0.67^{bc}	0.67^{ab}	3.00^{ab}	2.33^{a}	3.00^{ab}	3.33^{a}	3.00^{ab}	3.33^{a}
S1So3	1.33^{abc}	0.00^{b}	4.00^{ab}	2.00^{a}	4.00^{ab}	3.00^{a}	4.00^{ab}	3.00^{a}
S1C4	1.33^{abc}	0.00^{b}	2.67^{ab}	1.00^{a}	2.67^{ab}	1.67^{a}	2.67^{ab}	2.00^{a}
S1So4	1.67^{abc}	1.00^{a}	3.00^{ab}	3.00^{a}	3.00^{ab}	4.33^{a}	3.00^{ab}	4.33^{a}
S1C3	1.67^{abc}	0.00^{b}	2.00^{b}	0.67^{a}	2.00^{b}	1.67^{a}	2.00^{b}	1.67^{a}
S1C1	2.00^{ab}	1.00^{a}	2.00^{b}	1.67^{a}	2.00^{b}	2.67^{a}	2.00^{b}	2.67^{a}
S1So1	2.00^{ab}	0.67^{ab}	3.67^{ab}	3.00^{a}	3.67^{ab}	4.00^{a}	3.67^{ab}	4.00^{a}
S1So2	2.33^{a}	0.00^{b}	5.33^{a}	1.67^{a}	5.33^{a}	2.67^{a}	5.33^{a}	2.67^{a}
P Value	0.005	<0.00	0.015	0.302	0.015	0.419	0.018	0.223

Within the column means followed by different letters are significantly different at p <0.001.

S1C= sole sorghum in control; S1So1= alternate rows with soybean, S1So2= alternate holes with soybean; S1So3= same hole with soybean; S1So4= alternate with double rows of soybean; S1C1= alternate rows with cowpea; S1C2= alternate holes with cowpea; S1C3= same hole with cowpea; and S1C4= alternate with double rows of cowpea: DAP= Days after plating.

The results in Table 6 indicated that spatial arrangements differ in their performance, and that sorghum tillering is influenced by these patterns. Similar unearthing was reported by Hassan *et al.*, (2017) who found out that the number of tillers or branches of grasses and legumes are affected by intercropping. Generally, Hassan *et al.*, (2017) concluded out that pearl millet plants as grasses, either solid planting or their intercropped planting gave the highest number of tillers/plant. As well, the present study affirms the revelations of Ibrahim (1994) who found that sorghum had produced a greater number of tillers when grown in mixture with cowpea than in sole cropping. In addition, this study revealed that the number of sorghum tillers ranged from 1 to 4 when planted in alternate rows/ holes with soybean, while sorghum in same hole with soybean season one and with alternate rows with soybean season exhibited high number of tillers which was 4. This is in line with Hammer *et al.*, (1993) who revealed that sorghum may have zero to four fertile tillers depending on growing conditions and variety. Furthermore, the number of emerged tillers per plant increased linearly with thermal time for the duration of tiller emergence at each intercropping pattern. Similar findings were reported by Lafarge and Hammer (2002).

Number of leaves

The number of leaves presented in Table 7 exhibited significant differences at p <0.001 across the study period. Sorghum and soybean intercropping system in alternate holes had significantly a greater number of leaves averaging 13.33 than the rest in the 120 days after planting. This translated to 110% more leaves compared with sole sorghum. Also, intercropping patterns performed differently with sorghum in alternate holes with cowpea and sole sorghum performance lagged behind. This could be due to limited niche overlap in rooting over time and space and competition for nutrients remaining below threshold for negative impacts. The results are supported by those of Chundawat (1997) who reported the higher number of leaves plant^{-1} of sorghum when grown in mixture with clusterbean. Renwick *et al.*, (2020) ascertained that superior maize-pigeon pea performance across growing conditions was due to more efficient use of soil water, nutrient, and light, and competition for soil water and nutrients remaining below thresholds for negative impacts on whole-system, and N facilitation of maize by legumes through decomposition of legume residue which releases the mineralized N for maize uptake.

Table 7: Effect of intercropping sorghum with soybean and cowpea on number of leaves

Number of leaves								
	30 DAP		**60 DAP**		**90 DAP**		**120 DAP**	
Treatment	**Season 1**	**Season 2**	**Season 1**	**Season 2**	**Season 1**	**Season 2**	**Season 1**	**Season 2**
S1C2	3.00^{b}	6.00^{a}	3.67^{e}	8.00^{ab}	8.33^{cd}	11.00^{ab}	9.00^{d}	10.00^{ab}
S1C1	3.00^{b}	2.67^{bc}	3.67^{e}	4.33^{cd}	6.67^{e}	7.33^{cd}	7.67^{e}	8.33^{bc}
S1So1	3.00^{b}	5.67^{a}	4.67^{d}	10.00^{a}	7.67^{de}	12.00^{a}	8.67^{de}	12.00^{a}
S1C	3.00^{b}	2.00^{c}	3.67^{e}	3.33^{d}	6.33^{e}	6.33^{cd}	6.33^{f}	7.33^{c}
S1C3	3.33^{b}	5.33^{a}	4.67^{d}	7.00^{b}	8.67^{bcd}	7.33^{cd}	9.67^{cd}	8.33^{bc}
S1So3	3.67^{b}	4.67^{ab}	5.67^{c}	6.67^{bc}	9.67^{bc}	7.67^{cd}	10.67^{bc}	8.00^{bc}
S1C4	5.33^{a}	4.00^{abc}	7.33^{b}	4.33^{cd}	11.67^{a}	6.00^{d}	11.33^{b}	7.00^{c}
S1So4	6.33^{a}	5.33^{a}	8.33^{a}	6.67^{bc}	10.00^{b}	8.33^{cd}	11.00^{b}	11.67^{a}
S1So2	6.33^{a}	3.67^{abc}	8.33^{a}	7.33^{b}	12.33^{a}	8.67^{bc}	13.33^{a}	9.00^{bc}
P Value	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001

Within the column means followed by different letters are significantly different at p <0.001.

S1C= sole sorghum in control; S1So1= alternate rows with soybean, S1So2= alternate holes with soybean; S1So3= same hole with soybean; S1So4= alternate with double rows of soybean; S1C1= alternate rows with cowpea; S1C2= alternate holes with cowpea; S1C3= same hole with cowpea; and S1C4= alternate with double rows of cowpea: DAP= Days after planting.

To assess the effects of intercropping sorghum with soybean and cowpea on yield and yield components of sorghum

Table 8 shows that means of number of harvested heads, weight of harvested heads, and grain weight were statistically significant at p<0.001. Sorghum in alternate holes with soybean registered the maximum number of harvested heads of 21.33 and 19.67 in season one and two respectively translating to 113.3% and 136.13% more heads respectively as compared with sole sorghum. Similar trend was registered in weight of harvested head such that 1.93 and 1.71 Kgs was recorded in season one and two respectively, a translation of 22.15% and 256.25% higher than the sole sorghum. The same was observed in grain weight results which recorded 5.34 t ha^{-1} and 4.68 t ha^{-1} in season one and two respectively, an equivalent of 169.69% and 377.55% higher grain weight than sole sorghum.

The lowest number of heads averaging 10.00 and 8.33 were recorded in sole sorghum in season one and two respectively. This trend remained the same in grain weight where 1.98 t ha^{-1} and 0.98 t ha^{-1} was recorded in season one and two respectively. The improved performance of the mixed cropping system than sole cropping was attributed to better utilization of resources, particularly soil moisture and nutrients (Gare *et al*., 2009). Pal and Sheshu (2001) reported that intercropping of cereals with legumes also increased the productivity per unit of land area due to the atmospheric nitrogen biological fixation (BNF) that took place in the root nodules of legumes. The results were not similar to those of Arshad *et al.*, (2020) who reported that grain yield of sweet sorghum intercropped with soybean (5.2 t ha^{-1}) was at par with its sole crop (5.1 t ha^{-1}) because in this study there was a very wide gap between the two.

Table 8: Effect of intercropping sorghum with soybean and cowpea on number of harvested heads (NHH), weight of harvested heads (WHH) and grain weight (GW)

	NHH		WHH (Kgs)		GW (t/ha)	
Treatment	**Season 1**	**Season 2**	**Season 1**	**Season 2**	**Season 1**	**Season 2**
S1C	10.00^{d}	8.33^{e}	1.58^{ab}	0.48^{d}	1.98^{d}	0.98^{e}
S1So1	11.00^{cd}	13.33^{bc}	1.68^{ab}	0.39^{d}	2.69^{cd}	1.41^{de}
S1C1	12.67^{bcd}	10.00^{de}	1.41^{abc}	1.68^{ab}	2.49^{cd}	2.36^{bcde}
S1C3	13.00^{bc}	12.00^{bcd}	0.65^{cd}	0.65^{cd}	3.44^{bc}	2.44^{bcde}
S1C2	14.67^{b}	11.00^{cd}	0.49^{d}	1.41^{bcd}	2.4^{cd}	1.82^{cde}
S1C4	15.00^{b}	14.33^{b}	0.88^{bcd}	0.88^{bcd}	3.89^{b}	3.55^{abc}
S1So3	19.00^{a}	18.33^{a}	1.36^{abcd}	0.76^{cd}	3.84^{b}	2.84^{bcd}
S1So4	19.67^{a}	18.33^{a}	1.35^{abcd}	0.69^{cd}	4.51^{ab}	3.85^{ab}
S1So2	21.33^{a}	19.67^{a}	1.93^{a}	1.71^{a}	5.34^{a}	4.68^{a}
P Value	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001

Within the column means followed by different letters are significantly different at p <0.001.

S1C= sole sorghum in control; S1So1= alternate rows with soybean, S1So2= alternate holes with soybean; S1So3= same hole with soybean; S1So4= alternate with double rows of soybean; S1C1= alternate rows with cowpea; S1C2= alternate holes with cowpea; S1C3=same hole with cowpea; and S1C4= alternate with double rows of cowpea.

Sorghum in alternate holes with soybean had the maximum number of harvested heads that is 21.33 and 19.67, weight of harvested heads of 1.93 and 1.71 kgs and grain weight of 5.34 and 4.68 t ha^{-1} than the rest. This is an indicator that soybean as an intercrop did not exert pressure on sorghum, but instead, there was some mutual cooperation as shown in Table 4.7. This could also be due to the fact that greater competition was exerted by sorghum crop for resources over the legumes. The height and greater canopy sorghum also helped them to intercept more light than legume. The findings are aligned with those of Schwerdtner, (2022) thesis which showed that intercropping resulted in maize over yielding and enhanced maize N and P contents in the field, especially in soy/maize and lupin/maize intercropping, as compared to maize mono-cropping. He further noted that Maize over yielding was mainly caused by belowground interspecific interactions in legume/maize intercropping.

This study is in contrast with that of Langat *et al.,* (2006) whose findings indicated that intercropping significantly affected the yield of sorghum in sorghum/ groundnut intercropping. Gitari *et al.,* (2020) also found out that the yield was superior in pure stands (potato/legumes) than the intercropping systems and the decrease in the yield of the intercropped potato was ascribed to the intense interplant competition. In this study, conducive environment for plant could have been realized though the selection of the right plant spacing which supported the sorghum intercrops over the sole sorghum.

LER and ATER of different intercropping patterns

Effect of intercropping on LER

LER mean values were significant at p<0.001 as influenced by intercropping patterns as shown in Figure 1. LER values of the intercrop both in soybeans and cowpeas were greater than 1.0 as compared to those of sole sorghum, sorghum in same hole with cowpea and sorghum in alternate hole with cowpea an indicator of the advantages in intercropping system in the two seasons. The higher total LER of 1.82 and 1.73 were obtained from sorghum in alternate holes with soybean in seasons one and two respectively. This translated to 82% and 73% yield advantage in season one and two respectively compared to check treatment (sole sorghum crop). As well in comparison with all the intercrops, the check treatment registered the lowest LER (0.86) and (0.76) in season one and two respectively.

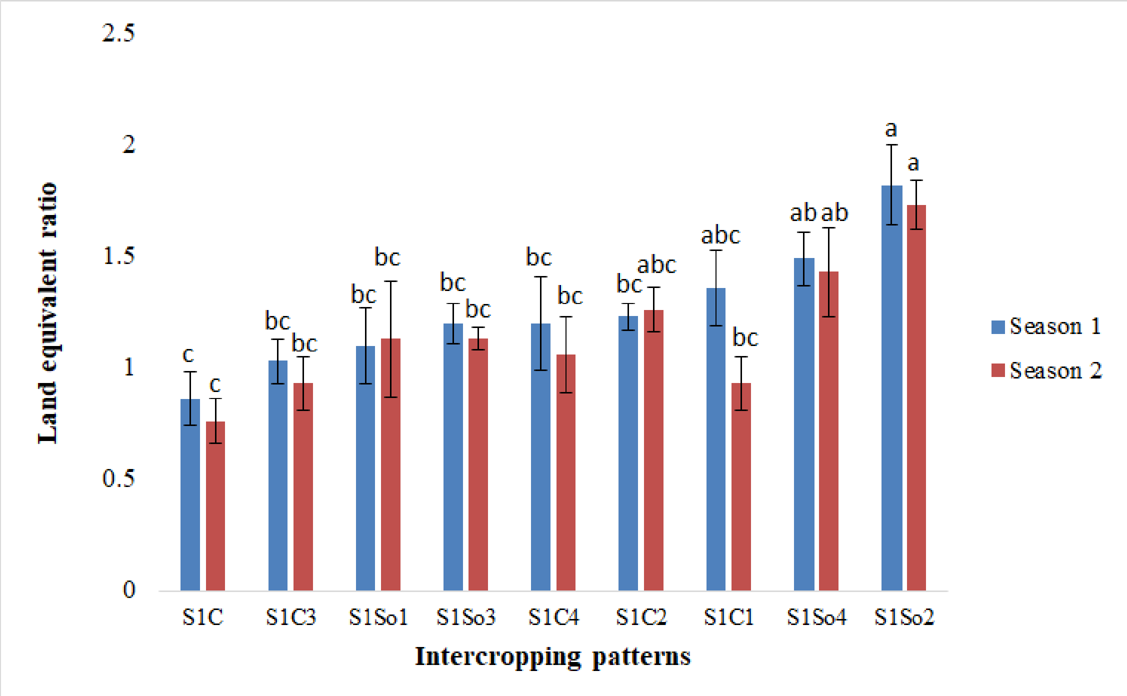

Figure 1: Effect of intercropping on land equivalent ratio

S1C= Sole sorghum in control; S1So1= alternate rows with soybean, S1So2= alternate holes with soybean; S1So3= same hole with soybean; S1So4= alternate with double rows of soybean; S1C1= alternate rows with cowpea; S1C2= alternate holes with cowpea; S1C3= same hole with cowpea; and S1C4= alternate with double rows of cowpea.

The intercrops especially of sorghum with soybean as well recorded positive results as compared with sole crop. Similar results were obtained by Ullah *et al.*, (2007) who reported a higher LER in maize/soybean intercropping than sole cropping. These current findings also collaborates with those of Caballero *et al.*, (1995) who reported a mixed stand advantage at lower oat seeding proportions in common vetch-oat combination. Also, Yadav & Yadav (2001) results are in agreement since their study demonstrated that, compared with corresponding sole crops, yield advantages pearl millet-cluster bean was recorded. Additionally, Kinde *et al.*, (2015) also reported higher LER results in sorghum/cowpea and soya bean intercrop than sole crop. Furthermore, soy enhanced AGB production and grain yield of associated maize resulting in a global mean LER of 1.32 for soy/maize intercropping (Chen *et al.*, 2019; Xu *et al.*, 2020). The yield advantage for intercropping could be due to the effective use of growth resources by the intercropped crops or the intercropping advantages of nitrogen fixation and increased light use efficiency than their counter parts (sole crops).

Effect of intercropping patterns on ATER

Data on ATER of sorghum intercrops shown in Figure 2 exhibited significantly higher results at $p<0.001$ as compared with sole crop. The highest ATER scores of 1.86 and 1.75 in seasons one and two respectively were calculated in sorghum in alternate holes with soybean an indicator of positive results. Meanwhile the lowest score of 0.7 and 0.66 was recorded in sole sorghum, thus indicating the disadvantage in sole cropping. Thus, ATER provides a more realistic comparison of the yield advantage of intercropping over sole cropping.

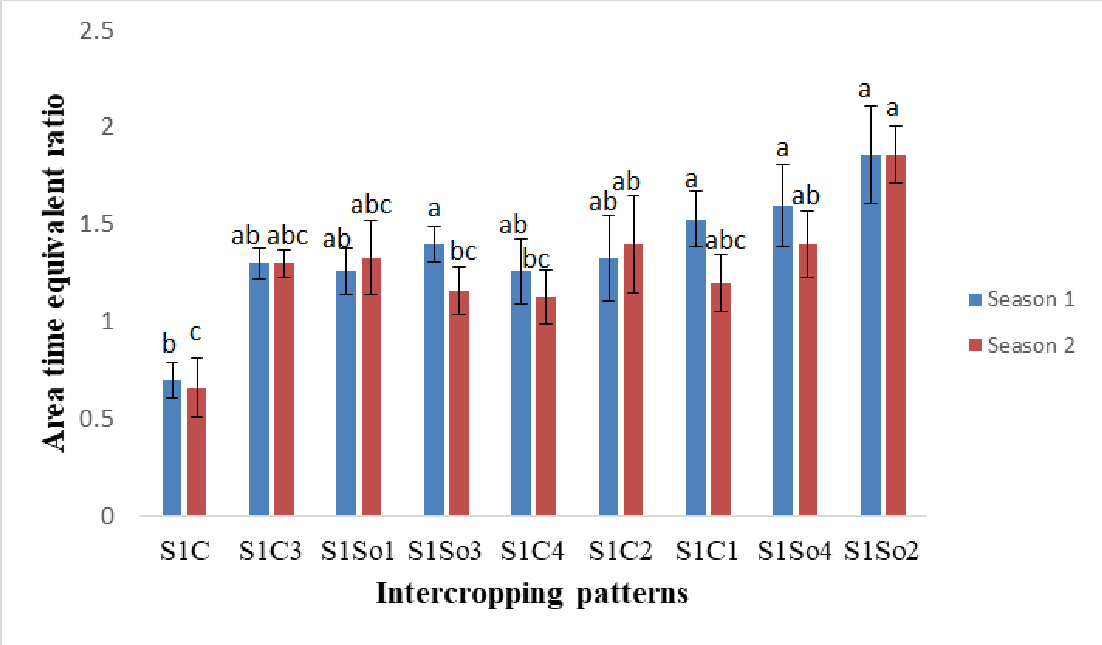

Figure 2: Effect of intercropping on area time equivalent ratio

S1C= Sole sorghum in control; S1So1= alternate rows with soybean, S1So2= alternate holes with soybean; S1So3= same hole with soybean; S1So4= alternate with double rows of soybean; S1C1= alternate rows with cowpea; S1C2= alternate holes with cowpea; S1C3= same hole with cowpea; and S1C4= alternate with double rows of cowpea.

The results in Figure 2 where the intercrops elicited higher ATER than sorghum sole crops could be due to the fact that intercropping gives more efficient, total resource exploitation and greater overall production than sole crops (compatible intercrops). Studies in support of the intercrops as compared with corresponding sole crops in terms of their yield advantages has been recorded in many non-legume-legume intercropping systems, including bean-wheat as confirmed by Hauggaard-Nielsen *et al.*, (2011), groundnut-cereal fodders by Ghosh, P.K. (2004) barley-pea by Chen *et al.*, (2004) and faba bean-barley by Trydemanknudsen *et al.*, (2004).

CONCLUSION

The findings revealed that sorghum-soybean intercropping in alternate pattern increased the yield advantage. Intercrops had considerable superior morphological traits than sole-cropping. In this way, intercropping sorghum with legumes offers a sustainable approach of enhancing crop productivity.

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