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Effect of plant population and row orientation on crop yield under sorghum-cowpea intercropping systems in semi-arid Zimbabwe

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Abstract

Smallholder farmers commonly practise intercropping to improve crop yield per unit land area. Proper combination of plant population and row orientation of the component crops needs to be established and this prompted this investigation. A 2x7 factorial experiment was laid in a RCBD with three replications, at Matopos Research Station in Natural Region IV of Zimbabwe. Treatments consisted of sorghum planted at a constant population of 55556plants/ha intercropped with cowpea (C) simultaneously planted at varying populations of 111111plants/ha (C1), 166667plants/ha (C3) and 222222plants/ha (C3) in East-West (EW) and North-South (NS) row orientation. Interaction of cowpea population density and row orientation significantly ($p<0.05$) influenced crop yield and its attributes. Treatment NS-SC3 produced lowest number of pods/plant and grains/pod of 2.6 and 6.1 respectively. Highest cowpea grain yield (637.2kg/ha) was obtained in EW-C3 and lowest (92.4kg/ha) in EW-SC3. Sorghum yield was highest in NS-S (1296.5kg/ha) and lowest in EW-SC3 (491.9kg/ha). LER showed that intercropping performed better than sole crops except for EW-SC3 and NS-SC3 which had LER of 0.800 and 0.905 respectively. Highest LER of 1.312 was obtained in EW-C2. Farmers should plant sorghum-cowpea intercrops in EW row orientation for increased cowpea grain yield but NS row orientation for sole sorghum.

Keywords: Intercropping, Intercrop population, Row orientation, LER

INTRODUCTION

Many rural households are currently food insecure and food demand is expected to increase in coming decades due to growing population and changing patterns of food consumption (Thornton *et al*., 2011). The food insecurity situation has been aggravated by numerous challenges faced since the late 1990s (USAID, 2020), alteration of temperature and rainfall pattern, drastic reduction in agricultural production following erratic rainfall and gross lack of key farming inputs (FAO/WFP, 2008). Furthermore, indigenous staple food crop production has declined in semi-arid Zimbabwe due to introduction of exotic cash crops during colonization (Muyambo and Shava, 2020). Production of main staple food crops is anticipated to grow less in coming decades if adaptation-based agriculture systems are not adopted (Lobell *et al*., 2008; Thornton *et al*., 2011).

Intercropping is one of these adaptation-based systems commonly practised by smallholder farmers in Zimbabwe with the potential contribution to weed management (Mandumbu and Karavira, 2012), improve crop yield and impacting positively to future food problems for smallholder farmers in the semi-arid regions of developing countries (Egbe, 2005). Intercropping is the practice of growing two or more crops simultaneously in the same field for entire or part of their growing period (Khanal *et al*., 2021). Intercropping is widely practised to increase efficiency of resource utilisation, reduce negative externalities of monoculture, improve agricultural productivity and reduce business risk (Bernard and Lux, 2017).

Practising intercropping increases productivity and yield in dry areas by increasing plant densities thus optimizing land use. The component crops should be adequately spaced to maximize production and reduce competition which can be accomplished by plant density, spatial arrangement, plant architecture, maturity dates of the crops grown (Banik *et al*., 2006) and row orientation (Kanjara *et al*., 2014). These gaps in intercropping have prompted this investigation.

MATERIALS AND METHODS

Site description

A field experiment was conducted at Matopos Research Station. The station is located about 40 kilometres south of Bulawayo city in South-West Zimbabwe on latitude 17°42^{1}01 64^{11} S and longitude 30°56^{1}33 24^{11} E and at an altitude of 1 353 m. The site is in Natural Region IV which receives annual rainfall of 400 - 650 mm. The area experiences mean annual minimum temperature range of 11-20^{0}C, mean maximum temperature range of 19-26^{0}C and mean annual temperature range of 18-24^{0}C (Mugandani *et al*., 2012). The site has red Fersiallitic loamy clay soils. Supplementary irrigation was provided when necessary.

Experimental design and treatments

The experiment was laid out in a 2 x 7 factorial arrangement of a Randomised Complete Block Design (RCBD) with three replications. The experiment consisted of 14 treatments (Table 1) namely four sole crops, sorghum (S) spaced at 90 x 20 cm (55 556 plants per hectare) and sole cowpea spaced at 45 x 20 cm (C1), 30 x 20 cm (C2) and 22.5 x 20 cm (C3) and three intercrop treatments of sorghum at 55 556 plants per hectare intercropped with cowpea at 111 111 (SC1), 166 667 (SC2) and 222 222 cowpea plants per hectare (SC3) in two row orientations; East-West (E-W) and North-South (N-S).

Table 1. Treatment structure

Row orientation	Intercrop population						
	S	C1	C2	C3	SC1	SC2	SC3
N-S	T1	T2	T3	T4	T5	T6	T7
E-W	T8	T9	T10	T11	T12	T13	T14

Gross plot dimensions were 71 m by 16 m (1 136 m^2) including 1 m boarders at all the edges of the plot and net plot was measuring 4 m x 4 m (16 m^2). At the edges of each plot, 2 boarder rows of sorghum were planted to avoid boarder effects. The field borders were cleared up to a width of 1 m and kept weed free to avoid the effect of the external environment.

Data collection

Cowpea yield and yield components

Number of pods per plant for five plants from each plot and number of grains per pod for five pods from each plot were determined at harvesting. Biomass and grain yield of cowpea were determined and recorded separately for each plot using an electronic scale.

Sorghum yield and yield components

Biomass and grain yield of sorghum were measured separately for each plot using an electronic scale.

Land Equivalent Ratio (LER)

LER was calculated to determine the intercrop advantage. It measures the effectiveness of intercropping in utilization of resources compared to sole cropping (Dhima *et al*., 2007; Takim, 2012). LER is the sum of fractions of intercrop yields divided by the sole crop yield and can be used as an agronomical index for assessing yield advantages derived from intercropping. The index is calculated as follows;

$$\mathrm{LER} = \frac{I_a}{S_A} + \frac{I_b}{S_B}$$

Where

I_a = intercrop yield of crop A

I_b = intercrop yield of crop B

S_A = sole crop A yield

S_B = sole crop B yield

A LER greater than 1.0 shows that intercropping is more efficient than sole cropping and a LER less than 1.0 shows that intercropping is disadvantageous. Willey (1985) indicated that a LER of 1.25 can be interpreted as 25% greater yield for intercropping or as 25% greater area requirement for the monocrop system.

Data analysis

Analysis of variance (ANOVA) was done using Genstat version 14th Edition (2013). Separation of means at α = 5% was done using Fischer's Least Significant Difference (LSD) where significant differences were noted (p-value < 0.05). The Land Equivalent Ratio (LER) was used to determine the intercrop advantage.

Results

Effect of cowpea population density and row orientation on cowpea pods per plant

Interaction effects of cowpea population density and row orientation significantly (P<0.001) influenced the number of pods per plant. The number of pods per plant ranged from 2.6 in the treatment sorghum intercropped with cowpea at 222 222 plants/ha in NS row orientation (NS-SC3) to 12.6 in treatment with sole cowpea at 111 111 plants/ha in EW row orientation (EW-C1). Generally, EW row orientation produced the highest number of pods per plant, ranging from 3.0 to 12.6 as compared to the NS row orientation which produced 2.6 to 5.7 pods per plant (Figure 1). Increasing the cowpea population density from 111 111 to 166 667 plants/ha resulted in 7.7 % and 25.0 % increase in the number of pods per plant for EW and NS row orientation, respectively. Further increase of the population of cowpea from 166 667 to 222 222 plants/ha in both sole and intercropped treatments in NS and EW row orientation, reduced the number of pods/plant. The number of pods per plant in intercropped treatments were reduced by 35.0% and 28.6% in EW and NS row orientation respectively compared to sole cropping.

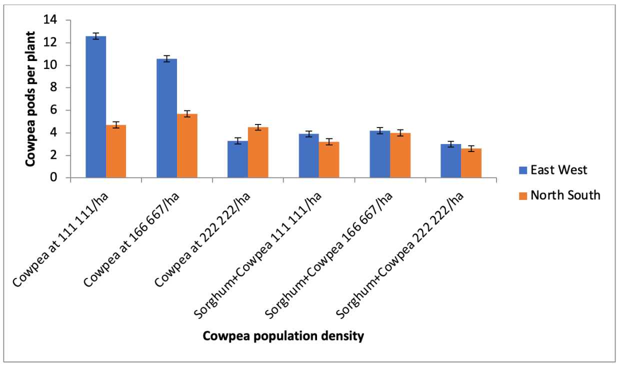

Figure 1. Effect of cowpea population density and row orientation on cowpea pods per plant in sorghum-cowpea intercropping systems

Effect of intercrop population and row orientation on number of cowpea grains per pod

Interactive effects of cowpea population density and row orientation significantly (P<0.001) influenced cowpea grains per pod (Figure 2). The treatment with sorghum intercropped with cowpea at 111 111 plants/ha and EW row orientation (EW-SC1), sole cowpea at 166 667 plants/ha and EW row orientation (EW-C2), sole cowpea at 111 111 plants/ha and NS row orientation (NS-C1) and sole cowpea at 166 667 and NS row orientation (NS-C2) produced the highest number of grains per pod ranging from 13.3 to 13.6 which were not significantly different from each other. The lowest cowpea grain number per pod of 6.1 was produced in treatment with the highest cowpea population density and NS row orientation (NS-SC3). The results also show that intercropping gave lower number of grains than sole cropping, with the NS row orientation giving lower yields than EW.

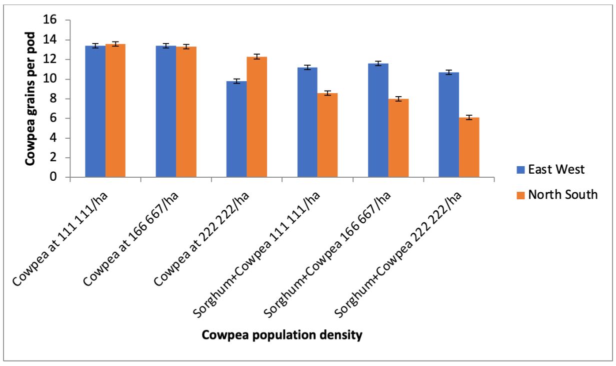

Figure 2. Effect of cowpea population density and row orientation on cowpea grains per pod in sorghum-cowpea intercropping systems

Effect of cowpea population density and row orientation on cowpea biomass

Cowpea biomass yield was significantly (P<0.001) influenced by the interaction effects of cowpea population density and row orientation (Figure 3). The biomass was generally higher, ranging from 368.5 to 578.5 kg/ha, under sole cowpea cropping in EW row orientation than under intercropping in both EW and NS row orientation which recorded low cowpea biomass ranging from 303.3 to 398.4 kg/ha.

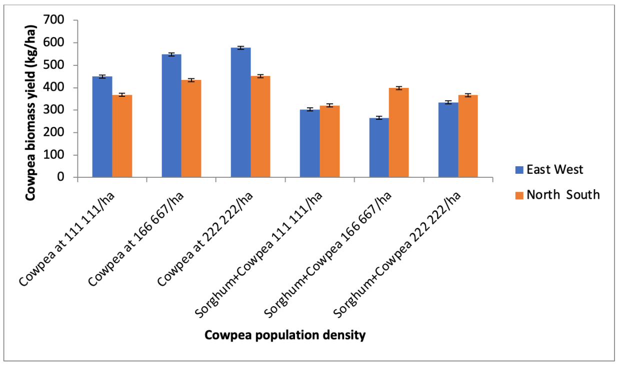

Figure 3. Effect of cowpea population density and row orientation on cowpea biomass yield in sorghum-cowpea intercropping systems

Effect of cowpea population density and row orientation on cowpea grain yield

The grain yield of cowpea was significantly (P<0.001) influenced by the interaction of cowpea population density and row orientation (Figure 4). The cowpea grain yield was higher in the treatments with sole cowpea in the EW row orientation ranging from 405.0 to 637.2 kg/ha and was lower in the treatments with intercropped cowpea in NS row orientation ranging from 92.4 to 206.3 kg/ha. The least grain yield of 92.4 kg/ha was produced in the treatment with highest cowpea population density in the NS row orientation (NS-SC3) and the highest cowpea grain yield of 637.2 kg/ha was produced in the treatment with sole cowpea in EW row orientation. The lowest cowpea grain yield was 88.5 % lower than the highest cowpea grain yield. The results also indicated that cowpea intercropping with highest population density produced significantly lower grain yield which was 70.9 % and 81.5 % lower in EW and NS row orientation respectively compared to their corresponding sole crops.

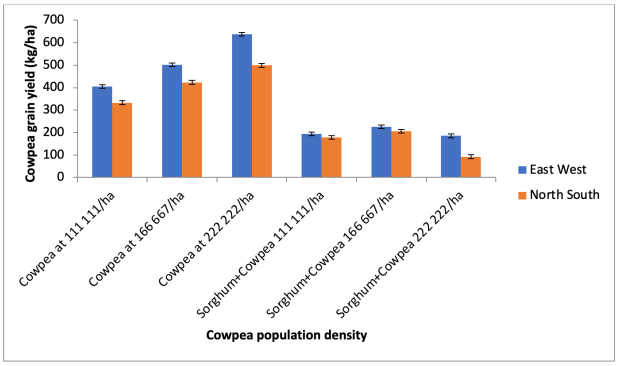

Figure 4. Effect of cowpea population density and row orientation on cowpea grain yield in sorghum-cowpea intercropping systems

Effect of cowpea population density and row orientation on sorghum biomass

Sorghum biomass was significantly (p<0.05) influenced by the interaction of row orientation and cowpea population density (Figure 5). Sole sorghum in both NS and EW row orientation (NS-S and EW-S) produced biomass which was significantly higher than that under intercropping, with sole sorghum in NS orientation producing significantly higher biomass than EW orientation. The lowest sorghum biomass of 1 366.4 kg/ha was produced in the treatment with cowpea intercrop at 111 111 plants/ha planted in EW row orientation, but was not significantly different from all the intercropped treatments. The highest sorghum biomass yield of 2487.4 kg/ha was produced in treatment with sole sorghum in NS row orientation.

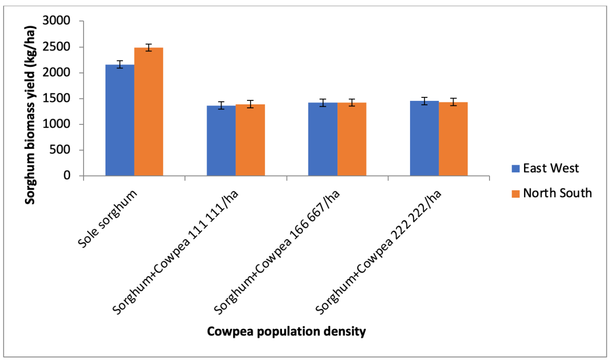

Figure 5. Effect of cowpea population density and row orientation on sorghum biomass in sorghum-cowpea intercropping systems

Effect of cowpea population density and row orientation on sorghum grain yield

Interaction between cowpea population density and row orientation significantly (P<0.001) influenced sorghum grain yield (Figure 6). Increasing the cowpea population density from 111 111 to 166 667 plants/ha produced significantly higher grain yields which were ranging from 906.4 to 988.5 kg/ha in NS row orientation compared to 491.9 to 831.9 in EW row orientation. The highest grain yield of 1 296 kg/ha was produced in sole sorghum planted in NS row orientation and the lowest sorghum grain yield of 491.9 kg/ha was produced in sorghum intercropped with cowpea at 222 222 plants/ha (highest cowpea population density) and planted in EW orientation. There was higher sorghum yield in sole sorghum in both row orientation which decreased by 29.2% and 30.1% with the introduction of the lowest cowpea population density of 111 111 plants/ha (SC1). As the cowpea population density was increased from 111 111 to 166 667 plants/ha, sorghum yield increased by 21.7% and 9.9% in EW and NS row orientation respectively. Sorghum yield decreased significantly by 40.9% and 5.6% in EW and NS row orientation respectively when cowpea population density was increased beyond critical of 166 667 (SC2) plants/ha (SC2).

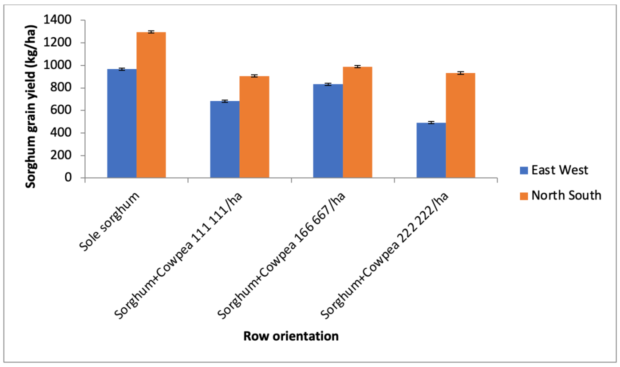

Figure 6. Effect of cowpea population density and row orientation on sorghum grain yield in sorghum-cowpea intercropping systems

Comparison of the productivity of sorghum-cowpea intercropping with that of sole crops using the Land Equivalent Ratio (LER)

The intercrop performance relative to the sole crop showed that sorghum-cowpea intercropping system performed better than sole crop except for those with highest cowpea population density planted in either EW or NS row orientation which had LERs of 0.800 and 0.905 respectively (Table 2). The intercrop system with the highest LER was the one with 166 667 cowpea plants/ha in EW row orientation. Sorghum with cowpea population density of 222 222 plants/ha in EW row orientation had the lowest LER. When the cowpea population density was increased from 111 111 to 166 667 cowpea plants/

ha, the LER increased by 10.4% from 1.188 to 1.312 in EW row orientation and by 1.2% from 1.233 to 1.248 in NS row orientation. The results also indicate that further increase in the cowpea population density from 166 667 to 222 222 plants/ha, reduced the LER by 31.4 and 27.6% in EW and NS row orientation respectively resulting in LERs which are less than a unit.

on interception by the plant canopy and soil moisture and nutrient uptake by the crops (Tsubo & Walker, 2003).

This reduction in biomass and grain yield as the cowpea intercrop population is increased can be attributed to severe intra-specific and interspecific competition for growth resources such as soil moisture, solar radiation,

Table 2. LERs for sorghum intercropped with varying population density of cowpea

Treatment	Partial LER		LER
	Sorghum	Cowpea	
EW-Sorghum + cowpea at 111 111 plants/ha	0.480	0.708	1.188
EW- Sorghum + cowpea at 166 667 plants/ha	0.451	0.861	1.312
EW- Sorghum + cowpea at 222 222 plants/ha	0.291	0.509	0.800
NS- Sorghum + cowpea at 111 111 plants/ha	0.536	0.699	1.235
NS- Sorghum + cowpea at 166 667 plants/ha	0.487	0.762	1.249
NS- Sorghum + cowpea at 222 222 plants/ha	0.185	0.720	0.905

DISCUSSION

Effect of cowpea population density and row orientation on cowpea yield and yield attributes

The number of pods per plant was higher in the sole cowpea as compared to the intercropped cowpea. This can be attributed to the absence or reduced interspecific competition which led to the production of more branches and probably taller plants with more pod/plant and higher number of grains per pod as compared to the intercropped plants. The reduction in number of pods per plant in intercropped cowpea plants could also, presumably, be attributed to better growth of the more aggressive sorghum plants during the dry spells which might have outcompeted the cowpea plants for radiation. More and well-distributed rainfall could have produced taller cowpea plants which would access more solar radiation allowing the crops to produce more pods per plant, number of grains per pod and yield more biomass and grain yield.

Cowpea biomass and grain yield reduction in intercropping might be due to the aggressive effects of sorghum plant on cowpea, similar to the case of reduced number of pods per plant under intercropping. Sorghum which is a C_4 plant probably had the ability to out compete cowpea which is a C_3 plant, for resources during the long dry spell experienced during the growing season resulting in lower biomass and grain yield for the cowpea crop. Crops with C_4 photosynthetic pathways have been known to be dominant when intercropped with C_3 crop species like cowpea (Hiebsch *et al*., 1995). The yield reduction of intercropped cowpea can also be attributed to the shading effect of taller sorghum plants as reported by Egbe (2010) who alluded that the photosynthetic rate of the lower growing plants can be reduced by the shading of the taller growing plants in a mixture thereby reducing the final grain yield. Interaction between plant population and row orientation influences solar radiation

nutrients and air between the intercrop components. In addition to these factors, depressive effects like shading from sorghum plants and high population density have also contributed to the decrease in the cowpea grain yield as reported by Egbe (2010). Pal *et al*. (1992) and Muoneke *et al*. (2007) reported similar yield reductions in Benue State, Nigeria in soybeans intercropped with maize and sorghum and associated the yield depression to interspecific competition and the depressive effect of cereals. These results were further explained by Ghosh (2004) in a report where the differences in yield were reported to be due to the differences in canopy height of soyabean and sorghum and added that the two species did not only compete for nutrients and water but also for sunlight.

Row orientation also influences the interception of solar radiation by the plant canopy. Borger *et al*. (2010) found that light influences flowering and fruit set thereby significantly determining number of pods per plant, number of grains per plant and crop productivity. This implies that light is a determinant of both biomass and grain yield. Reducing the crop row spacing or changing the crop row orientation at near right angle to the sunlight direction (NS) increases shading of the intercrop (cowpea) by the main crop (sorghum). Cowpea yields achieved in this research were far less than the varietal yield potential of 4 000 kg/ha reported by DR&SS (2015). The differences in yield can be due to differences in soil fertility and the poor rainfall season.

Effect of cowpea population density and row orientation on sorghum yield

There was higher biomass and grain yield in sole sorghum than in sorghum-cowpea intercrops probably due to absence of or reduced competition under the former system. This is in contrast to Lemlem (2013) and Mashingaidze (2004) who independently observed the attainment of higher yield under intercropping systems due to more efficient utilisation of resources available. Pathak *et al*. (2013) reported higher total green fodder yield in sorghum intercropped with cowpea in 2:1 row ratio. Competition for resources such as nutrients, soil moisture, air, solar radiation and space is reduced under sole cropping than under intercropping if same plant population for the main crop is maintained. When cowpea intercrop population was increased from 166 667 to 222 222 plants/ha there was a reduction in both biomass and grain yield and this could be due to the plant density of cowpea which had exceeded the optimum for intercropping. In intercropping, the plant density should be optimised to reduce competition from overcrowding by adjusting the seeding rate of each crop on the mixture below the full rate to allow the crops to yield well in the mixture as reported by Hiesbick, (1980) and Prabhakar, *et al*. (1983). These results are similar to those found by Kanjara *et al.* (2014). The results are also similar to those found by Tsubo *et al.* (2003) who reported that maize crops oriented in NS row orientation intercepted more Photosynthetically Active Radiation (PAR), increasing the rate of photosynthesis and thereby increasing the ear length, ear weight and grain yield in maize-beans intercrop experiments in semi-arid conditions of South Africa.

Generally, row orientation produced contrasting results for sorghum and cowpea biomass and grain yields. NS row orientation produced significantly higher sorghum biomass and grain yield than the EW oriented intercrop crops. On the contrary, EW row-oriented crops produced higher cowpea biomass and grain yield than NS oriented crops. This can be attributed to more solar radiation interception by the taller sorghum plants resulting in increased photosynthesis and consequently more dry matter and grain yields production. Cowpea plants in NS row orientation received less solar radiation due to more shading effects of the taller sorghum plants.

Comparison of the productivity of sorghum-cowpea intercropping with that of sole crops using the Land Equivalent Ratio (LER)

Land Equivalent Ratio (LER) was used to determine yield advantage of intercropping. The results indicated that intercropping had advantages up to a cowpea population density of 166 667 plants per hectare as indicated by the LERs which are greater than 1. The LERs which are less than a unity in the treatments with higher cowpea population mean that there was more competitive interference than complementary facilitation. This indicates that the performance of the intercrop was affected by competition from the cowpea component. The treatments which resulted in a LER above 1 had yield advantage as compared to sole cropping and the results could stem from low interspecific competition or strong facilitation (Kipkemoi *et al*., 1997). Intercropping was found to be more beneficial (indicated by LER greater than a unit) in less fertile fields and more marginal environments compared to fertile fields (Kermah *et al*. (2017). Choudhary *et al*. (2016) observed that intercropping increased land-use efficiency by 17-53 % and produced a LER of 1.21-1.56.

According to Van der Meer (1989) it is possible to obtain the net result of Land Equivalent Ratio (LER) where the complimentary facilitation is contributing more to the interaction of the crop species intercropped than the competitive interaction since both competition and facilitation take place in many intercropping systems. Thus, a LER < 1 could result from high interspecific competition or weak to no facilitation while a LER > 1 could result from low interspecific competition and strong facilitation among the intercropped crop species.

CONCLUSION

The yield and yield components of both the main crop (sorghum) and the intercrop (cowpea) were significantly influenced by the interaction of cowpea population density and row orientation. The treatment which had sole cowpea at 166 667 plants/ha in EW row orientation produced the highest number of pods per plant and the treatment which had sorghum intercropped with cowpea at 222 222 plants/ha in NS row orientation produced the least number of pods per plant. The least cowpea biomass and grain yields were produced in the treatment which had sorghum intercropped with cowpea at 166 667 plant /ha while sole cowpea at 222 222 plants/ha produced the highest cowpea biomass. The highest sorghum biomass and grain yield was produced in the treatment which had sole sorghum in NS row orientation (N-S) and the least sorghum biomass and grain yield was produced in the treatment which had sorghum with cowpea at 222 222 plants/ha in EW and NS row orientation, respectively. The LER results indicated that sorghum-cowpea intercrop systems performed better than their corresponding sole crops except for the treatments which had the highest cowpea population density of 222 222 plants/ha in both EW and NS row orientation which had LERs of 0.800 and 0.905 respectively.

Recommendations

We recommend farmers in Matobo District and other semi-arid areas to plant cowpea intercrops in sorghum under the ES row orientation at populations ranging from 111 111 to 166 667 plants/ha to produce relatively high yields from cowpea plants as it allows more light penetration and interception by the cowpea canopy. This row orientation would enhance higher light interception hence higher photosynthesis by cowpea plants and ultimately produce better yields that would vary depending on amount of rainfall received. LER which is above unit for the same treatment combinations further supports this recommendation. Sorghum-cowpea intercrops should be planted in EW row orientation to enhance sorghum yield and NS row orientation for sole sorghum. More studies are recommended across rainfall season, soil types, agroecological regions and varietal or crop diversity to fully appreciate the effects of cowpea population density and row orientation on crop yield.

COMPLIANCE WITH ETHICAL STANDARDS

Conflict of interest

Authors do not declare any conflict of interest.

Author contribution

The contribution of the authors to the present study is equal.

All the authors read and approved the final manuscript. All the authors verify that the Text, Figures, and Tables are original and that they have not been published before.

Ethical approval

Ethics committee approval is not required.

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Data availability

Not applicable.

Consent for publication

Not applicable.

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