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Effect of row spacing under maize-soybean relay intercropping system on yield, competition, and economic returns

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Abstract: Interrow spacing of intercrop species directly affects yield and competition indices such as land equivalent ratio of intercropping. The objectives of this research were to analyze (i) the maize and soybean yields under different spatial arrangements in maize-soybean relay strip intercropping (MSR) and (ii) the interspecies competition to provide a basis for optimization of row-spacing in MSR. The field trial was conducted in 2011 and 2012 at the Research Farm of the Sichuan Agricultural University in Ya'an to determine the impacts of various interrow planting distances on yield and competition indices in cereal (maize crop)-legume (soybean crop) relay strip intercropping. Three planting arrangements were utilized based on the distance between maize-maize, maize-soybean, and soybean-soybean as (**T1**) 50, 40, and 70 cm, (**T2**) 50, 50, and 50 cm, and (**T3**) 50, 60, and 30 cm, respectively, and comparison was made with the sole maize (SM) and sole soybean (SSB). Experimental results revealed that grain yield of maize crop was improved with enhancing row spaces between maize and soybean, while "low-high-low" trend was observed for soybean yield in T_1, T_2, and T_3, respectively, in both years. Competitive ratio, aggressivity, and relative crowding coefficient were consistently greater for maize than soybean in all treatments. The highest LER (1.67) was reported in T_2 treatment, which was 9% and 4% higher than in T_1 and T_3, respectively. Higher LER explains that both crops are facilitating each other in a positive way and increase the average net income of T_2 as compared to T_1 and T_3. Enhancing distance between maize-soybean rows with reducing distance between soybean rows put pressure on soybean due to intraspecific competition. Combined results of competitive indices and economic analysis showed that intercrops performed at their maximum in treatment T_2. Therefore, the maximum intercropping advantages can be achieved by changing the row spacing, which determines the competitive relationship and productivity of MSR.

Key words: Maize, soybean, intercropping, interrow distance, competition, yield

1. Introduction

Intercropping and relay-intercropping are among major cropping systems used worldwide to achieve high yields in grain crops (Ghaffarzadeh et al., 1994; Dhima et al., 2007; Chen et al., 2017; Raza et al., 2019a; Ton and Anlarsal, 2019). Different crops share the same field during a given

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period of time and at contrasting growth stages in the relay-intercropping approach (Raza et al., 2019b) for increased land equivalent ratio (Raza et al., 2019c). In southwestern China, the maize-soybean relay intercropping system (MSR) is a dominant cropping system (Yang et al., 2014; Iqbal et al., 2019) due to its high LER, which can be as high as 1.6 (Du et al., 2018), compared to a world average of 1.34 (Yu et al., 2015).

In intercropping systems, increased competition for light, nutrients, water, or any combination of the three elements, eventually alters crops productivity in comparison to monocropping (Carruthers et al., 2000). Because of the immobility of plants, both crops need to have suitable time and space to perform better under the competitive environment with the adjacent allospecific neighbor (Stoll and Weiner, 2000; Oseni et al., 2010). Therefore, in intercropping systems, assessing the level of competition between crops is vital in the determination of an optimum planting pattern, as two crops share the time and space in the field (Figure 1).

Several indices have been developed for comparison of sole crop and intercrop production including the land equivalent ratio, relative crowding coefficient, competitive ratio, actual yield loss, aggressivity, monetary advantage index, and intercropping advantage (Banik et al., 2000; Yilmaz et al., 2008). However, there is lack of information on use of such indices under varying row distances between maize-soybean and soybean-soybean to evaluate the competition, as well as the yield advantage of each intercropping system.

In MSR, early sowing crop is maize, while late sown crop is soybean. Maize is a tall crop, whereas soybean is a short crop (Echarte et al., 2011). Therefore, plants of maize dominate in light environment of field and combined with other factors results in higher yields in the MSR compared to sole cropping system (Chen et al., 2017; Yang et al., 2017; Raza et al., 2019b; Raza et al., 2019c). Since soybean light environment is affected by the maize plants because it is planted about two months later and at narrower rows than maize, usually a severe competition for available resources takes place between the two crops in the phase of the initial growth period of soybean (Cui et al., 2014; Yang et al., 2014; Fan et al., 2018; Feng et al., 2019; Khalid et al., 2019). Maize shading adversely influences the morphological parameters, physiological traits, as well as biochemistry-based processes of intercropped soybean plants in the MSR. Yield and biomass are ultimately affected due to various row distances in the maize-soybean intercropping system (Wu et al., 2017; Raza et al., 2019a; Raza et al., 2020a). Consequently, in comparison to sole soybean, intercropped soybean produces a lower seed yield in the MSR (Liu et al., 2017; Iqbal et al., 2019). Spatial plant variations for MSR have been studied (Undie et al., 2012; Yang et al., 2015; Yang et al., 2017; Raza et al., 2019) but narrow row spacing of the soybean-soybean along with the alterations in maize-soybean row distance in MSR have not been studied. Such a research study is

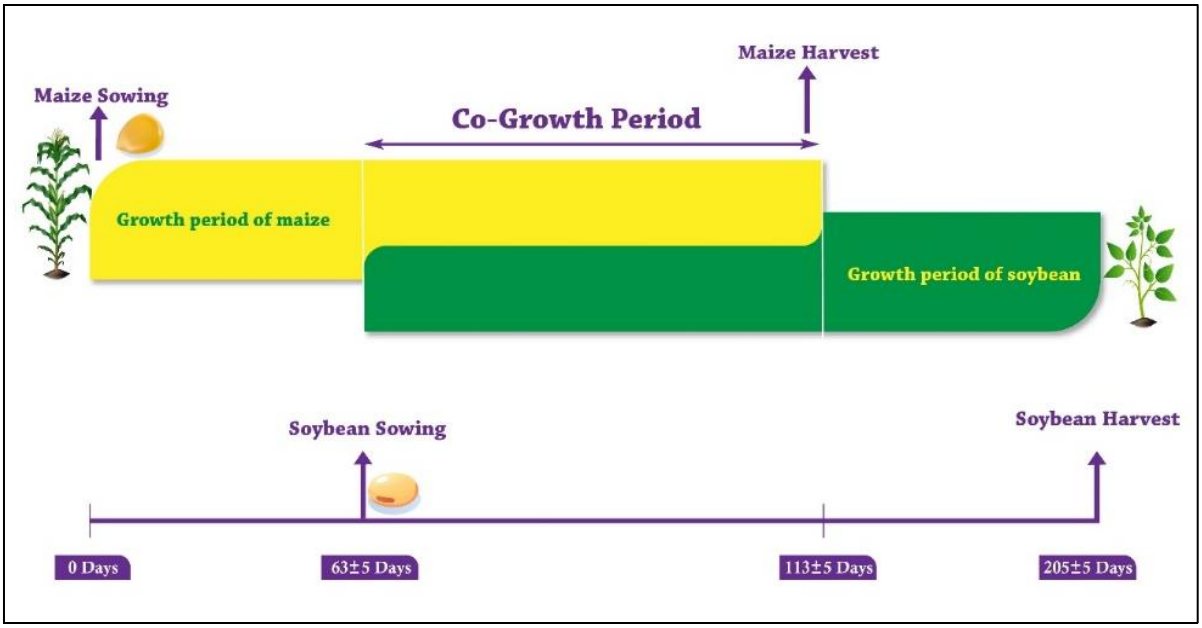

Figure 1. Illustration of the overlapping growth period of maize-soybean relay intercropping system. The upper bar represents the growing period of maize (113 ± 5 days, first sown relay-crop), and the lower bar shows the growing period of soybean (142 ± 5 days, second sown relay-crop). The cogrowth period (50 ± 5 days) is defined as the proportion of the total system growth period (205 ± 5 days) in which both relay-crops grow together.

indispensable to understand the factors that affect the yield in intercropping systems, such as in MSR.

Previous research has shown that the sole crop row-spacing is important under environmental stresses (Battaglia et al., 2018, 2019a, b). More information is needed for the optimization of soybean row-spacing in MSR to adjust the light environment and decrease both the nutritional competition and yield gaps between actual production and production potential for both crops in relay intercropping system. The purposes of this investigation were to analyze (i) the maize and soybean yields under different spatial arrangements in MSR and (ii) the interspecies competition to provide a basis for optimization of row-spacing in MSR.

2. Materials and methods

2.1. Study location

Field experiment was carried out at the Research Farm of the Sichuan Agricultural University in Ya'an (29°59′ N, 103°00′ E), Sichuan Province, China during 2011 and 2012. The region had a humid subtropical climate and frostless period lasted approximately 300 days. Weather data such as averaged air temperature (°C), rainy days, rainfall (mm), relative humidity (%), and clouds (%) of the area from March to November is given in Figure 2. The soil texture was classified as clay loam, and had available soil organic matter quantity of 29.9 g kg^{-1}, nitrogen (N) of 64.7 mg kg^{-1}, available phosphorus (P) of 17.8 mg kg^{-1}, and available potassium (K) of 96.5 mg kg^{-1} in experimental soil.

2.2. Experimental design

The field study comprised 5 planting patterns with 3 replications using a randomized block design. These planting patterns varied with respect to the distances among rows of maize and soybean crops and within soybean rows under intercropping systems and monocultures of both crops. The staggered arrangement of 2M:2S (2 rows of each crop were altered with each other) was followed in intercropping. By adopting the utmost appropriate bandwidth of 200 cm (Yang et al., 2015), three distance variation treatments were used as shown in Figure 3, the distance maize-maize, maize-soybean, and soybean-soybean was (**A**) 50, 40, and 70 cm, (**B**) 50, 50, and 50 cm, and (**C**) 50, 60, and 30 cm, respectively. Sole maize and sole soybean were used as control treatments

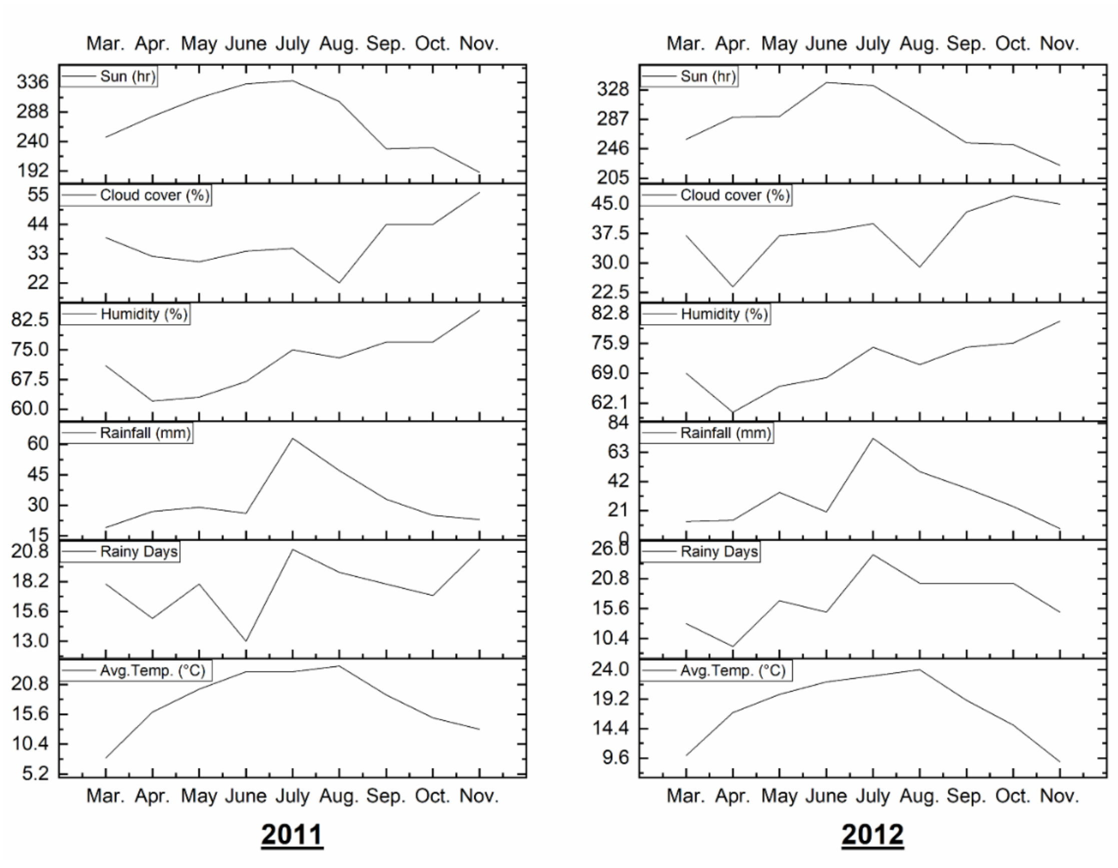

Figure 2. Monthly average temperature (°C), rainy days, rainfall (mm), humidity (%), and clouds (%) from March to November in the growing seasons of 2011 and 2012.

with row distances of 100 and 50 cm, respectively (Figure 3), which are the distances commonly used in the study area, given that the light intensity and interception is low and the level of humidity and rainfall is relatively higher compared with other areas in the country.

Every plot was measured as 6 m long and 6 m wide giving an area of 36 and had three strips such that it accommodated 2 maize and 2 soybean rows per strip. In this study, the varieties used for maize and soybean were 'Chuandan-418' (semicompact) and 'Gongxiang-1' (late maturing), respectively. Sowing of maize was on April 3rd in 2011 and April 5th in 2012, whereas respective sowing dates for soybean were June 13, 2011 and June 15, 2012 at the V12 stage of maize crop (Abendroth et al., 2011). Maize was reaped on July 29th in 2011 and on August 1st in 2012. The soybean crop was harvested on October 30, 2011 and on November 2, 2012. The plant densities (both in intercrop and pure stand plots) were 10 and 6 plants per square meter for soybean and maize, respectively. Prior to maize and soybean sowing, phosphorus (P) as calcium superphosphate was used at a quantity of 40 and 40 kg ha^{-1}, potassium (K) in the form of potassium

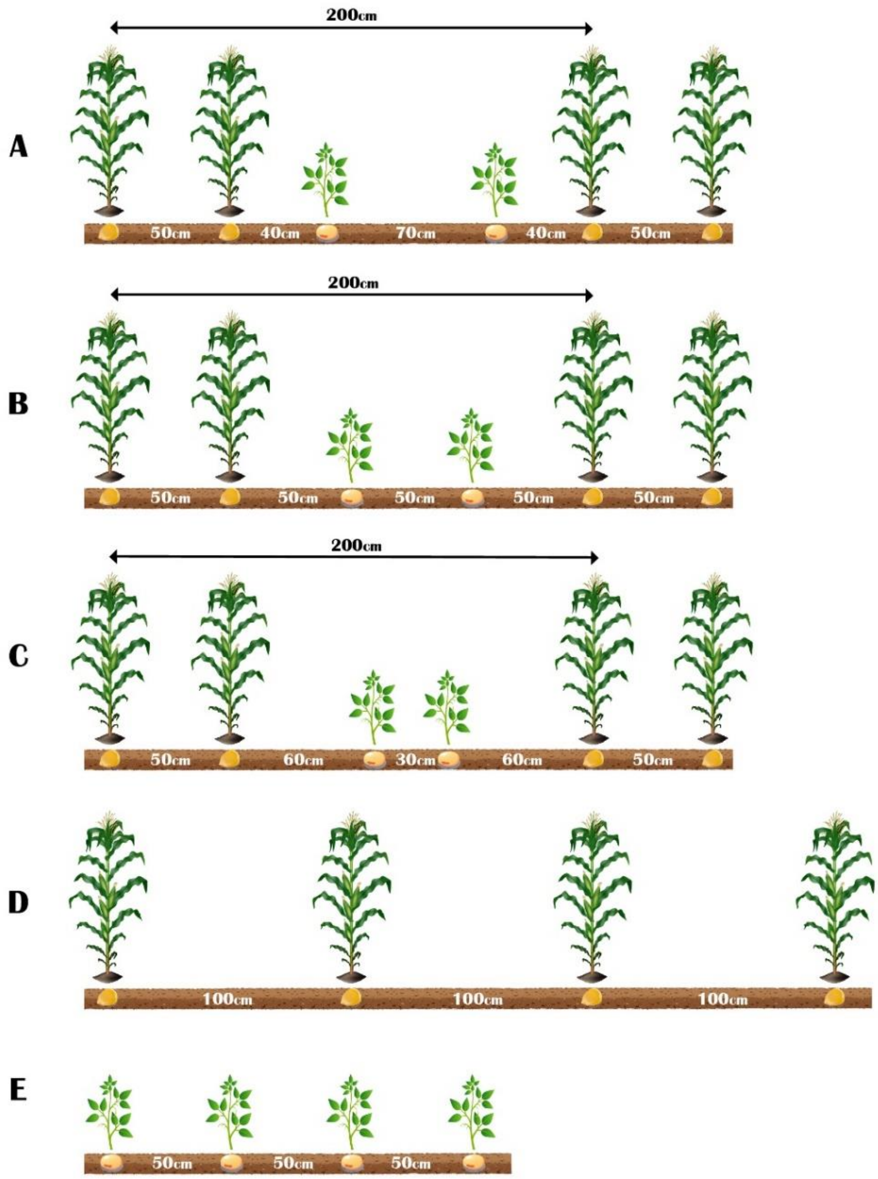

Figure 3. Layout of the spatial arrangements for the maize-soybean relay intercropping systems. In the three planting patterns utilized in this research, distances for maize-maize, maize-soybean, and soybean-soybean were (**A**) 50, 40, and 70 cm, (**B**) 50, 50, and 50 cm, and (**C**) 50, 60, and 30 cm, respectively. **D and E** represent the sole maize (SM) and sole soybean (SSB), respectively.

sulfate at 10 and 4 kg ha^{-1}, and basal nitrogen (N) as urea at quantities of 135 and 75 kg ha^{-1} were manually used and incorporated, respectively. At the V6 stage of maize and the R1 stage (starting of anthesis stage) of soybean (Fehr and Caviness, 1977), N (urea) at the quantities of 135 and 75 kg ha^{-1} was manually spread in field, respectively. Weeds were manually controlled 3 times at an interval of 20 days starting 20 days after emergence, whereas other agronomic practices were carried out according to the local farmer's practices.

2.3. Competition indices and monetary advantages

2.3.1. Grain yield and system productivity index

In the intercropping systems, grain yields were harvested from a 10-m^2 area (5-m-long by 2-m-wide) of the plot middle strips to avoid border effects, while 2 rows of 5 m in length were harvested in the sole cropping systems. The grain yield of each plot was sampled and weighted individually. The maize and soybean grain yields were determined after air-drying to a moisture content of approximately 15%. Finally, according the prtocol described by Odo (1991), the system productivity index (SPI) was determined by the following equation:

$$SPI = \left(\frac{SA}{LB} \times Lb\right) + Sa, \quad (1)$$

where SA indicates the yield of sole maize and LB indicates the yield of sole soybean, whereas Sa denotes the yield of intercropped maize and Lb denotes the yield of intercropped soybean.

2.3.2. Land equivalent ratio

This competition index was computed as the aggregate of intercropped yields in comparison to sole reference crops (Huxley and Maingu 1978), as suggested by (Fetene 2003):

$$LER_t = \left(LER_{maize} + LER_{soybean}\right), \quad (2)$$

$$LER_{maize} = \left(\frac{Y_{im}}{Y_{sm}}\right), \quad (3)$$

$$LER_{Soybean} = \left(\frac{Y_{is}}{Y_{ss}}\right), \quad (4)$$

where LER_t, LER_{maize}, and $LER_{soybean}$ are the total combined and the partial LERs of maize and soybean, respectively. Y_{sm} indicates the yield of sole maize and Y_{im} indicates the yield of intercropped maize (Mg ha^{-1}), while Y_{ss} indicates the seed yield of sole soybean and Y_{is} indicates the seed yield of intercropped soybean (Mg ha^{-1}).

2.3.3. Relative crowding coefficient

It is denoted by RCC or K measures aggressiveness of one species toward another and was calculated according to Firbank and Watkinson (Firbank and Watkinson 1985) as follows:

$$K_m = \frac{Y_{im} \times F_s}{(Y_{sm} - Y_{im}) \times F_m}, \quad (5)$$

$$K_s = \frac{Y_{is} \times F_m}{(Y_{ss} - Y_{is}) \times F_s}, \quad (6)$$

where Y_{sm} and Y_{ss} are monoculture maize yield and monoculture soybean yield, and Y_{im} and Y_{is} are intercropped maize and soybean yields, respectively. The F_s and F_m coefficients indicate the sown proportion of land for soybean and maize in intercropping, respectively.

2.3.4. Competitive ratio (CR)

As an index, the CR provides a more necessary competitive ability for the crops compared with K (Dhima et al., 2007). CR is more advantageous and measured the competitive ability of the crops in a better way. It was calculated by:

$$CR_{maize} = \left(\frac{\mathrm{LER}_{\mathrm{maize}}}{LER_{soybean}}\right)\left(\frac{Z_{sm}}{Z_{ms}}\right), \quad (7)$$

$$CR_{soybean} = \left(\frac{LER_{soybean}}{\mathrm{LER}_{\mathrm{maize}}}\right)\left(\frac{Z_{ms}}{Z_{sm}}\right). \quad (8)$$

CR_{maize} (CR_m) less than 1 implies a positive benefit and the possibility of growing crops together, whereas CR_{maize} greater than 1 implies a negative impact. The opposite is true in the case of $CR_{soybean}$ (CR_s). Z_{ms} indicates the sown proportion of land for maize, and Z_{sm} indicates the sown proportion of soybean crop in relay intercropping technology.

2.3.5. Aggressivity

Aggressivity reveals interspecific competition through relating change in yields of 2 component crops in intercropping (Agegnehu et al., 2006). It is computed by the subsequent formula:

$$A_{ms} = \left(\frac{Yms}{Y_m Z_{ms}}\right) - \left(\frac{Ysm}{Y_s Z_{ms}}\right), \quad (9)$$

$$A_{sm} = \left(\frac{Y_{sm}}{Y_s Z_{sm}}\right) - \left(\frac{Y_{ms}}{Y_m Z_{ms}}\right). \quad (10)$$

If A_m = 0, both crops have an equal degree of competitiveness. On the other hand, a positive A_{ms} or A_{sm} implies that either maize or soybean is the dominant crop in the intercropping system.

2.3.6. Actual yield loss (AYL)

The partial AYL_{maize} or $AYL_{soybean}$ describe the relative decline in the yield of maize or soybean, respectively, per sowing proportion in intercropped maize-soybean in comparison with corresponding yields in sole crops (Banik et al. 2000). The total (sum of partial AYL for maize and soybean) and the partial AYLs are calculated as follows:

$$AYL = AYL_{maize} + AYL_{soybean}, \quad (11)$$

$$AYL_{maize} = \left\{\left[\frac{Y_{im}/Z_{im}}{Y_m/Z_{mm}}\right] - 1\right\}, \quad (12)$$

$$AYL_{soybean} = \left\{ \left[\frac{Y_{is}/Z_{is}}{Y_s/Z_{ss}} \right] - 1 \right\}. \quad (13)$$

An overall positive AYL represents the advantage, whereas a negative AYL represents the disadvantage of an intercropping system.

2.3.7. Economic indices

The economic advantage of the intercropping system was calculated as follows:

$$MAI = \frac{(value\ of\ combined\ intercrops) \times (LER - 1)}{LER}. \quad (14)$$

The intercropping advantage (IA) was computed using the equation below:

$$IA_{maize} = AYL_{maize} \times P_{maize}, \quad (15)$$

$$IA_{soybean} = AYL_{soybean} \times P_{soybean}, \quad (16)$$

where P_{maize} indicates the commercial maize value (the price was €153.27 per Mg) and $P_{soybean}$ indicates the commercial soybean value (the price was €378.35 per Mg). Overall, a higher IA and MAI value means a more profitable cropping system (Ghosh, 2004).

2.4. Economic analysis

The economic assessment of the various planting patterns in this study was performed using partial budgeting. Local rates of both crops' seeds, fertilizers (nitrogen, phosphorus, and potassium), land rent, seedbed preparation, thinning as well as weeding, and maize and soybean harvesting and threshing were estimated to this end. Local market prices of both crops during the first year (2011) and the second year (2012) were multiplied by the measured yields of both crops in each year to calculate the gross income (GI). Net income (NI) was computed through subtraction of all the expenditures from gross income (Raza et al., 2019). Moreover, benefit–cost ratio (BCR) analysis was performed to ascertain economic variability of each cropping pattern.

2.5. Statistical analysis

Analysis of the studied parameters was done by using one-way ANOVA with the SPSS software (version 15, SPSS Inc., Chicago, IL, USA). The ANOVA was performed in Statistix 8.1 using a randomized complete block design with three treatments that were replicated three times. The treatment means were separated and tested through post hoc comparisons using the Student-Newman Keuls test significant difference (LSD) at a significance level of $p \leq 0.05$.

3. Results

3.1. Yields and SPI of the different intercropping systems

In both years, insignificant difference was found between the yield of sole and intercrop maize (Table 1). However, production of sole soybean was higher than the intercrop soybean, which varied significantly among all the treatments. Soybean yield in T_2 was higher as compared with T_1 and T_3, with the increase in 24.2% and 5.4%, respectively. Stability of any sole or intercropping system depends upon its productivity. According to the system productivity index (SPI), among all the treatments, T_2 was the most productive

Table 1. Grain yields and system productivity index (SPI) of the different maize-soybean relay strip intercropping systems in 2011 and 2012.

Years	Cropping System	Grain yield (Mg ha^{-1})			SPI
		Maize	Soybean	Total	
2011	T_1	7.60 ^{a}	0.90 ^{d}	8.5 ^{c}	11.53 ^{c}
	T_2	7.62 ^{a}	1.15 b	8.77 ^{a}	12.64 ^{a}
	T_3	7.64 ^{a}	1.08 c	8.71 ^{b}	12.33 ^{b}
	SM	7.67 ^{a}	—	7.67 ^{d}	—
	SSB	—	1.76 ^{a}	1.76 ^{e}	—
2012	T_1	7.75 ^{a}	1.00 ^{d}	8.75 ^{c}	14.09 ^{c}
	T_2	7.76 ^{a}	1.21 ^{b}	8.98 ^{a}	15.45 ^{a}
	T_3	7.78 ^{a}	1.16 ^{c}	8.94 ^{b}	15.14 ^{b}
	SM	7.81 ^{a}	—	7.81 ^{d}	—
	SSB	—	1.80 ^{a}	1.80 ^{e}	—

Different letters in the same line column indicate significant differences between the treatments of maize and soybean at $\alpha = 0.05$. For different maize-soybean relay strip intercropping systems, the distances for maize-maize, maize-soybean, and soybean-soybean were 50, 40, and 70 cm (T_1), 50, 50, and 50 cm (T_2), and 50, 60, and 30 cm (T_3), respectively. SM and SSB refer to the sole maize and the sole soybean cropping systems, respectively. Means in the same column followed by different letters are different at the 0.05 probability level.

and stable cropping pattern followed by T_3 and T_1.

3.2. Land equivalent ratio

The mean LER values of all the treatments in maize-soybean relay intercropping system were more than one regardless of interrow spacing treatments, revealing higher yield, as well as land advantage, in comparison to sole maize and sole soybean. The MSRI is more advantageous than sole cropping system with the maximum LER of >1.6 (Figure 4). The partial LER of maize (LER_m) had no significant differences in entirely relay intercropping systems. However, partial LER of soybean (LER_s) varied considerably, and LER_s in T_2 was higher than in T_1 and T_3. The total LER was significantly different in all the treatments, and the mean value of LER was 1.67 in T_2, which was the highest among all the treatments, and the mean LER values in T_1 and T_3 were 1.53 and 1.61, respectively, which are 8.7% and 3.6% lower than T_1.

3.3. Relative crowding coefficient

The interspecific competitive abilities were computed with the help of RCC or K. According to the K values of all the relay intercropping systems, K_{maize} was always higher than $K_{soybean}$ during the two years in all treatments depicting the dominance (higher K) and superior competitiveness of maize over soybean. The $K_{soybean}$ values were increased (from 0.85 to 1.93 in the first year and 1.02 to 2.22 in the second year) with the enhancing distance between rows of maize and soybean, and highest $K_{soybean}$ was obtained in T_3 (Table 2).

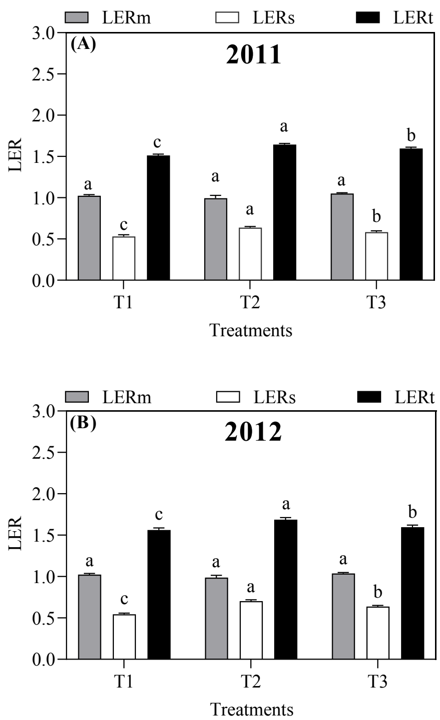

Figure 4. LER for the maize (LER_m) with soybean (LER_s) mixtures at three relay strip intercropping systems (T_1, T_2, and T_3) from 2011(**A**)–2012(B), where LERt shows the total LER of the system. The distance maize-maize, maize-soybean, and soybean-soybean was (T_1) 50, 40, and 70 cm, (T_2) 50, 50, and 50 cm, and (T_3) 50, 60, and 30 cm. The different letters within the same LER (bars with the same color in the three graphs) indicate the statistically significant differences at $p < 0.05$.

3.4. Competition indices

The values of A, CR, and AYL in all treatments are shown in Table 3. Different competitive behavior was observed in different treatments of planting distance based on the observed data of A and CR. In all treatments, maize was the dominant species by showing a positive value of A and CR >1. Aggressivity of maize crop towards soybean reduced with the enhancement in the distance between rows of maize and soybean. As competitive ratio of maize (CR_m) is decreasing with the enhancement of distance between rows of maize and soybean (T_1:40, T_2:50, and T_3:60) which relates to the decreasing distance between soybean rows (T_1:70, T_2:50, and T_3:30) and causes the increase in competitive ratio (CR_s) among soybean plants in both years of intercropping.

All the positive values of partial AYL of maize and soybean crop in intercropping revealed its yield advantage over monocropping of maize and soybean both crops in 2011 and 2012. The maximum and minimum values of total AYL (AYL_t) were observed in T_2 (+1.316, averaged data of 2 years) and T_1 (+1.051, averaged data of 2 years), respectively.

3.5. Intercropping advantage and monetary advantage index

The IA value reveals important information regarding economic feasibility of an intercropping system and highlights its advantage over sole cropping system. In all the treatments, positive values of IA showed its definite yield advantage over sole cropping (Table 4). Values of IA showed the "low-high-low" trend in T_1-T_2-T_3 treatments, respectively. The highest values were observed in T_2, which were 268.34 and 282.87 for 2011 and 2012, respectively. The minimum values (159.9 and 192.59 for 2011 and 2012, respectively) were observed in T_1 treatment.

MAI is another indicator of economic benefit of intercropping over sole cropping. The MAI values were also positive and followed a similar trend confirming vibrant benefit of intercropping as compared to sole cropping. The highest (210.98 € ha^{-1}, average data of two years) and lowest (183.1 € ha^{-1}) values of MAI were observed in T_2 and T_1 treatments, respectively.

3.6. Economic analysis

Table 5 indicated that the higher total income (1212 € ha^{-1} during the first year (2011) and 1178 € ha^{-1} during the second year (2012) was obtained in treatment T_2 under MSR, whereas the lower total income (275 € ha^{-1} during the first year and 306 € ha^{-1} in the second year was gained

Table 2. Relative crowding coefficient of soybean (Ks) and maize (Km) based on the different intercropping patterns. T_1 means that the distance between the maize and soybean is 40 cm, T_2 has a distance of 50 cm, and T_3 has a distance of 60 cm.

Years	Cropping system	Relative crowding Coefficient	
		K_{maize}	$K_{soybean}$
2011	T_1	151.39	0.857
	T_2	170.53	1.894
	T_3	216.80	1.934
2012	T_1	160.20	1.021
	T_2	171.81	2.061
	T_3	192.75	2.224

Table 3. Aggressivity, competitive ratios, and actual yield losses of the soybean and maize mixtures under different relay strip intercropping systems from 2011–2012.

Years	Cropping system	Aggressivity		Competitive ratio		Actual yield loss		
		A_{ms}	A_{sm}	CR_{ms}	CR_{sm}	AYL_{maize}	$AYL_{soybean}$	AYL_{total}
2011	T_1	0.637	–0.637	2.369	0.422	0.984	0.024	1.008
	T_2	0.340	–0.340	1.519	0.658	0.988	0.309	1.297
	T_3	0.225	–0.225	1.330	0.752	0.992	0.226	1.218
2012	T_1	0.598	–0.598	2.185	0.458	0.985	0.110	1.095
	T_2	0.382	–0.382	1.477	0.677	0.989	0.347	1.336
	T_3	0.188	–0.188	1.262	0.792	0.991	0.291	1.282

T_1 means that the distance between maize and soybean is 40 cm, T_2 has a distance of 50 cm, and T_3 has a distance of 60 cm.

Table 4. The intercropping advantage and monetary advantage indices for the soybean and maize mixtures under different relay strip intercropping systems from 2011–2012.

Year	Cropping system	Intercropping advantage			MAI
		IA_{maize}	$IA_{soybean}$	IA_{total}	
2011	T_1	150.82	9.08	159.9	178.10
	T_2	151.43	116.91	268.34	209.16
	T_3	152.04	85.51	237.55	201.24
2012	T_1	150.97	41.62	192.59	188.11
	T_2	151.58	131.29	282.87	212.81
	T_3	151.89	110.10	261.99	207.68

T_1 means that the distance between maize and soybean is 40 cm, T_2 has a distance of 50 cm, and T_3 has a distance of 60 cm.

in sole soybean (SSB) treatment. Overall, the average over the years of the total income was improved through 31% and 19% in T_2, in comparison to T_1 and T_3, respectively. Highest BCR values of 1.70 and 1.62 were observed in T_2 treatment as compared to 1.54 and 1.46 in T_1, and 1.60 and 1.51 in T_3 in 2011 and 2012, respectively.

4. Discussion

The yield improvement potential, along with the reduction in harmful impact, has been repeatedly demonstrated by the intercropping system (Aziz et al., 2015; Yu et al., 2015). Yield differences between relay intercropping and sole cropping systems may be caused by the competition

Table 5. Economic analysis of the soybean and maize mixtures under different relay strip intercropping systems from 2011–2012 according to the value of the currency (€) in respective years.

Treatments	Gross income (€/ha^{-1})		Net income (€/ha^{-1})		Benefit–cost ratio	
	2011	2012	2011	2012	2011	2012
T_1	2659.41	2796.84	937.18	885.62	1.54	1.46
T_2	2934.53	3088.74	1212.31	1177.52	1.70	1.62
T_3	2750.11	2895.48	1027.89	984.26	1.60	1.51
SM	1849.62	1982.17	716.29	724.46	1.63	1.58
SS	1252.52	1391.35	274.74	306.27	1.28	1.28

T_1 means that the distance between maize and soybean is 40 cm, T_2 has a distance of 50 cm, and T_3 has a distance of 60 cm.

efficiency of crops for available resources, including light interception (Li et al., 2001; Ross et al., 2004). Light environment and competition for available resources were directly affected due to various spacing between rows in intercropping approach (Farnham, 2001; Yang et al., 2017; Raza et al., 2019d). In maize-soybean intercropping approach, maize behaved as a dominant crop due to its more competitiveness for intercepted photosynthetically active radiations (Liu and Song, 2012; Feng et al., 2019). In this two-year study, the production of maize did not change significantly in intercropping treatments as compared to sole cropping, but soybean production was generally reduced. However, the yield of soybean in T_2 was much higher than T_1 and T_3. These results of system productivity index indicated that optimal maize-soybean relay strip intercropping pattern has a yield advantage compared with the maize or soybean monocultures. Resources use efficiency is enhanced due to relay intercropping with appropriate planting pattern (Borghi et al., 2013; Yang et al., 2017; Raza et al., 2019c), and intercropping have relatively stable productivity.

Land equivalent ratio can be very useful for the purpose of assessment of the competition relationship between component crops. The LERt values were higher than 1 in all treatments of strip-width in maize-soybean intercropping depicting its yield advantage over sole maize and soybean due to improved land productivity (Mead and Willey 1980; Yang et al., 2015). In this study, averaged values of LER in T_1, T_2, and T_3 were 1.53, 1.67, and 1.61, respectively, an implication that sole maize and soybean required 50% to 80% more land to balance production with it. Similar consequences were also obtained in other intercropping systems in China (Li et al., 2003; Mahmoudi et al., 2013; Ahmed et al., 2018; Feng et al., 2019; Raza et al., 2020b) where all the conclusions indicated that intercropping crops attained higher LER values when crops were sown at a suitable interrow distance in the intercropping systems, in which both crops can cause facilitation and complementation for each other in an improving way. Similarly, outcomes of our findings (treatment T_2 showed the highest LER of 1.67 where row spacing between maize-soybean and soybean-soybean was 50 cm each), which indicates that maximum production can be achieved by managing the best optimum row spacing between maize-soybean and soybean-soybean rows. Optimum row spacing can provide higher resource use efficiency, such as land use efficiency in relay intercropping approach.

In intercropping systems, yields are positively linked with competitiveness of component species. Less competition between intercrop species occurs under appropriate planting patterns (Li et al., 2001). Maize showed greater competitiveness than the soybean (Yang et al., 2015) and alfalfa (Zhang et al., 2011) in intercropping approach. In this study, similar results were observed as the values of K_{maize} were greater than those of $K_{soybean}$ (Table 2). The values for $\mathbf{A}_{\mathbf{ms}}$ and $\mathbf{A}_{\mathbf{sm}}$ were positive and negative, respectively, in all the treatments showing that cereal is more competitive in comparison to the corresponding legume crop as proven by preceding reports (Dhima et al., 2007; Yilmaz et al., 2008). It is also reported that CR is a well indicator of the competitive ability of intercrop species in comparison to the RCC or K, and A (Willey and Rao, 1980; Wahla et al., 2009). Values of competitive ratio are following the same trend as other competitive indices further confirming the competitive superiority of maize over soybean as described in previous reports (Yang et al., 2015; Liu et al., 2017). From T_1 to T_3, the row spacing between maize-soybean and soybean-soybean increases and decreases, respectively, which causes a decrease and an increase in the CR_m and CR_s, respectively. On the basis of inter- and intraspecific competition in intercropping, AYL index gives more accurate evidence regarding behavior of component crops (Banik et al., 2000). The partial AYL of maize was higher as compared with soybean showing the dominance of maize in MSI. In line with the previous studies, as the consequences of the high LER, maximum value of AYL was observed in T_2 where the distances between and within component crops are optimum (Yang et al., 2015). These results implied that optimum resource distribution and utilization cannot be achieved when the intraspecies competition of the intercropped soybean increases by decreasing distance between soybean-soybean rows. In addition, our results are in line with those of Franco and Harper (1988), whose results indicated that negative correlation in neighboring plants may be due to interplant competition. This interplant competition increases with the decrease in distance between and within maize and soybean rows.

The positive value of IA is the indicator of superiority of intercropping over sole cropping system. Moreover, higher values of MAI are also a positive indicator of the economic superiority of intercropping. In general, "low-high-low" trend was observed in the values of IA and MAI across all the treatments. While in specific, the maximum values of IA and MAI were observed in T_2 showing its superiority over other treatments. All other competition indices and LER confirmed the results of IA and MAI (Ghosh, 2004; Yang et al., 2017). In addition, in comparison to sole maize and sole soybean, treatments T_1, T_2, and T_3 improved the net income of MSR by 26% and 66%, 40% and 215%, and 312% and 247%, respectively. These consequences of the LER and the net income evidently reveal the more yield sustainability, land advantages, and net income of T_2 over T_1, T_3 and sole cropping systems under existing circumstances. Moreover, highest BCR (1.70) was also obtained in T_2 treatment while, least BCR (1.28) was obtained in SS. Overall, economic benefits of T_2 can be accredited to appropriate weak inter- and intraspecific competition in maize-soybean intercropping. Without distinction of one from others, intercropping systems remain an exciting and well choice to acquire higher component crop yields with more use of accessible resources as compared to sole cropping. However, these results suggested that we want to choose the optimal inter- and intrarow distances in MSR for sustainable production of cereals along with legumes.

5. Conclusion

Grain yield of intercrops is directly affected by planting patterns in maize-soybean relay strip intercropping. In this field experiment, grain yield of maize was not influenced significantly, but seed yield of soybean was influenced significantly. The aggressivity and competitive ratio of soybean increased by decrease in distance between rows of soybean caused by the increased distance between maize and soybean rows. Furthermore, RCC or K values of soybean increased as the intraspecies competition intensified. The productivity of intercropping soybean was affected due to row spacing between maize-soybean and soybean-soybean rows. When row distance of maize-soybean and soybean-soybean was 50 cm (T_2), soybean occupied a suitable ecological niche, and the obtained SPI, MAI, IA, and AYL values of soybean were highest. Additionally, LER in T_2 was higher than in T_1 and T_3, which indicated that the intercropping pattern in T_2 was the most stable for yield advantage due to better land-use efficiency and economics as compared to other planting arrangements. Therefore, our results showed that there is significant impact of row spacing on competition and grain yield of intercrops. However, further studies to find optimum row spacing are required to obtain high yields by improved utilization of growth resources of the component crops in maize-soybean intercropping. Moreover, plant spacing is as important as row spacing to increase or decrease land productivity and crop yield. Therefore, further combined studies of plant to plant and row to row spacing are required to obtain the maximum benefit from intercropping systems.

Author contributions

L.C., M.H.B.K, F.Y., and W.Y. carried out the design of the study and wrote this paper. M.H.B.K., L.C., and M.A.R. carried out the plant cultivation, chemical analysis, and statistical analysis of this work. M.A.R. participated in experiment management. M.A.R., G.A, A.A, Z.A, A.W, W.A, M.J.B, S.A, R.T, M.M.J, A.A.B, H.D., and W.Y. reviewed and edited this research paper.

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Conflict of interest

The authors declare no conflicts of interest

References

Abendroth LJ, Elmore RW, Boyer MJ, Marlay SK (2011). Corn growth and development. PMR 1009. Iowa State Univ. Extension and Outreach, Ames.

Agegnehu G, Ghizaw A, Sinebo W (2006). Yield performance and land-use efficiency of barley and faba bean mixed cropping in Ethiopian highlands. European Journal of Agronomy 25 (3): 202-207.

Ahmed S, Raza MA, Zhou T, Hussain S, Khalid MH et al. (2018). Responses of soybean dry matter production, phosphorus accumulation, and seed yield to sowing time under relay intercropping with maize. Agronomy 8 (12): 282-287.

Aziz M, Mahmood A, Asif M, Ali A (2015). Wheat-based intercropping: a review. Journal of Animal and Plant Sciences 25 (4): 896-907.

Battaglia ML, Lee C, Thomason W (2018). Corn yield components and yield responses to defoliation at different row widths. Agronomy Journal 110: 1-16.

Battaglia M, Lee C, Thomason W, Fike J, Sadeghpour A (2019a). Hail damage impacts on corn productivity: a review. Crop Science 59: 1-14.

Battaglia M, Lee C, Thomason W, Van Mullekom J (2019b). Effects of corn row width and defoliation timing and intensity on canopy light interception. Crop Science 59: 1718-1731.

Banik P, Sasmal T, Ghosal PK, Bagchi DK (2000). Evaluation of mustard (Brassica compestris Var. Toria) and legume intercropping under 1: 1 and 2: 1 row-replacement series systems. Journal of Agronomy and Crop Science 185 (1): 9-14.

Borghi EC, Crusciol CA, Nascente AS, Sousa VV, Martins PO et al. (2013). Sorghum grain yield, forage biomass production and revenue as affected by intercropping time. European Journal of Agronomy 51: 130-139.

Carruthers K, Prithiviraj B, Fe Q, Cloutier D, Martin RC et al. (2000). Intercropping corn with soybean, lupin and forages: yield component responses. European Journal of Agronomy 12 (2): 103-115.

Chen P, Du Q, Liu X, Zhou LI, Hussain S et al. (2017). Effects of reduced nitrogen inputs on crop yield and nitrogen use efficiency in a long-term maize-soybean relay strip intercropping system. PloS one 12 (9): e0184503.

Cui L, Su BY, Yang F, Yang WY (2014). Effects of photo-synthetically active radiation on photosynthetic characteristics and yield of soybean in different maize/soybean relay strip intercropping systems. Scientia Agricultura Sinica 47 (8): 1489-1501.

Dhima KV, Lithourgidis AS, Vasilakoglou IB, Dordas CA (2007). Competition indices of common vetch and cereal intercrops in two seeding ratio. Field Crops Research 100 (2-3): 249-256.

Du JB, Han TF, Gai JY, Yong TW, Xin SU et al. (2018). Maize-soybean strip intercropping: Achieved a balance between high productivity and sustainability. Journal of Integrative Agriculture 17 (4): 747-754.

Echarte L, Della Maggiora A, Cerrudo D, Gonzalez VH, Abbate P et al. (2011). Yield response to plant density of maize and sunflower intercropped with soybean. Field Crops Research 121 (3): 423-429.

Fan Y, Chen J, Cheng Y, Raza MA, Wu X et al. (2018). Effect of shading and light recovery on the growth, leaf structure, and photosynthetic performance of soybean in a maize-soybean relay-strip intercropping system. PloS one, 13 (5): e0198159.

Farnham D (2001). Row spacing, plant density, and hybrid effects on corn grain yield and moisture. Agronomy Journal 93 (5): 1049-1053.

Feng L, Raza MA, Chen Y, Khalid MH, Meraj TA et al. (2019). Narrow-wide row planting pattern improves the light environment and seed yields of intercrop species in relay intercropping system. PloS one 14(2) e0212885.

Fetene M (2003). Intra-and inter-specific competition between seedlings of Acacia etbaica and a perennial grass (Hyparrenia hirta). Journal of Arid Environments 55 (3): 441-451.

Firbank L, Watkinson A (1985). On the analysis of competition within two-species mixtures of plants. Journal of Applied Ecology 22 (2) 503-517.

Ghaffarzadeh M, Préchac FG, Cruse RM (1994). Grain yield response of corn, soybean, and oat grown in a strip intercropping system. American Journal of Alternative Agriculture 9 (4): 171-177.

Ghosh P (2004). Growth, yield, competition and economics of groundnut/cereal fodder intercropping systems in the semi-arid tropics of India. Field crops research 88 (2-3): 227-237.

Franco, M, Harper JL (1988). Competition and the formation of spatial pattern in spacing gradients: an example using Kochia scoparia. The Journal of Ecology, 959-974.

Huxley P, Maingu Z (1978). Use of a systematic spacing design as an aid to the study of inter-cropping: some general considerations. Journal of Experimental Agriculture 14 (1): 49-56.

Iqbal N, Hussain S, Ahmed Z, Yang F, Wang X et al. (2019). Comparative analysis of maize–soybean strip intercropping systems: a review. Plant Production Science 22 (2): 131-142.

Khalid M, Raza M, Yu H, Sun F, Zhang Y et al. (2019). Effect of shade treatments on morphology, photosynthetic and chlorophyll fluorescence characteristics of soybeans (Glycine max L. Merr.). Applied Ecology and Environmental Research, 17 (2): 2551-2569.

Li L, Sun J, Zhang F, Li X, Yang S et al. (2001). Wheat/maize or wheat/soybean strip intercropping: I. Yield advantage and interspecific interactions on nutrients. Field Crops Research 71 (2): 123-137.

Li L, Zhang F, Li X, Christie P, Sun J et al. (2003). Interspecific facilitation of nutrient uptake by intercropped maize and faba bean. Nutrient Cycling in Agroecosystems 65 (1): 61-71.

Liu T, Song F (2012). Maize photosynthesis and microclimate within the canopies at grain-filling stage in response to narrow-wide row planting patterns. Photosynthetica 50 (2): 215-222.

Liu X, Rahman T, Song C, Su B, Yang F et al. (2017). Changes in light environment, morphology, growth and yield of soybean in maize-soybean intercropping systems. Field Crops Research 200: 38-46.

Mahmoudi R, Jamshidi K, Pouryousef M (2013). Evaluation of grain yield of maize (Zea mays L.) and soybean (Glycine max L.) instrip intercropping. International Journal of Plant Production 4 (9): 2388-2392.

Mead R, Willey R (1980). The concept of a 'land equivalent ratio'and advantages in yields from intercropping. Journal of Experimental Agriculture 16 (3): 217-228.

Odo P (1991). Evaluating short and tall sorghum varieties in mixtures with cowpea in Sudan Savanna of Nigeria: LER, grain yield and system productivity index. Journal of Experimental Agriculture 27 (4): 435-441.

Oseni TO, Aliyu I (2010). Effect of row arrangements on sorghum-cowpea intercrops in the semi-arid savannah of Nigeria. International Journal of Agriculture and Biology 12 (1): 37-140.

Raza MA, Feng LY, Iqbal N, Ahmed M, Chen YK et al. (2019a). Growth and development of soybean under changing light environments in relay intercropping system. Peer Journal 7: e7262.

Raza MA, Feng LY, Khalid MH, Iqbal N, Meraj TA et al. (2019b). Optimum leaf excision increases the biomass accumulation and seed yield of maize plants under different planting patterns. Annals of Applied Biology 175 (1): 54-68.

Raza MA, Feng LY, van der Werf W, Cai GR, Khalid MH et al. (2019c). Narrow-wide-row planting pattern increases the radiation use efficiency and seed yield of intercrop species in relay-intercropping system. Food Energy Security 8(3): e170.

Raza MA, Feng LY, van Der Werf W, Iqbal N, Khalid MH et al. (2019d). Maize leaf-removal: A new agronomic approach to increase dry matter, flower number and seed-yield of soybean in maize soybean relay intercropping system. Scientific Reports. 9 (1): 1-13. Raza MA, Bin Khalid MH, Zhang X, Feng LY, Khan I, Hassan MJ, Ahmed M, Ansar M, Chen YK, Fan YF, Yang F. (2019e). Effect of planting patterns on yield, nutrient accumulation and distribution in maize and soybean under relay intercropping systems. Scientific Reports 9 (1): 1-14.

Raza MA, Feng LY, Iqbal N, Khan I, Meraj TA et al. (2020a). Effects of contrasting shade treatments on the carbon production and antioxidant activities of soybean plants. Functional Plant Biology 47 (4): 342-354.

Raza MA, Feng LY, van der Werf W, Iqbal N, Khan I et al. (2020b). Optimum strip width increases dry matter, nutrient accumulation, and seed yield of intercrops under the relay intercropping system. Food Energy Security 9 (2): e199.

Ross SM, King JR, O'Donovan JT, Spaner D (2004). Forage potential of intercropping berseem clover with barley, oat, or triticale. Agronomy Journal 96 (4): 1013-1020.

Stoll P, Weiner J (2000). A neighborhood view of interactions among individual plants. U. Dieckmann, R. Law, J.A.J. Metz (Eds.), The Geometry of Ecological Interactions, Cambridge University Press, Cambridge, pp. 11-27.

Ton A, Anlarsal AE (2017). The effects of different sowing system and ratios on grain yield and yield components and use environmental resources in intercropping of pea (Pisum sativum L.) and wheat (Triticum aestivum L.). Frensenius Environmental Bulletin 28(7): 5502-5511.

Undie U, Uwah D, Attoe E (2012). Effect of intercropping and crop arrangement on yield and productivity of late season maize/ soybean mixtures in the humid environment of south southern Nigeria. Journal of Agricultural Science 4 (4): 37-50.

Wahla IH, Ahmad R, Ehsanullah AA, Jabbar A (2009). Competitive functions of components crops in some barley based intercropping systems. International Journal of Agriculture and Biology 11 (1): 69-72.

Willey R, Rao M (1980). A competitive ratio for quantifying competition between intercrops. Journal of Experimental Agriculture, 16 (2): 117-125.

Wu Y, Gong W, Yang W (2017). Shade inhibits leaf size by controlling cell proliferation and enlargement in soybean. Scientific Reports 7 (1): 1-10.

Yang F, Huang S, Gao R, Liu W, Yong T et al. (2014). Growth of soybean seedlings in relay strip intercropping systems in relation to light quantity and red: far-red ratio. Field Crops Research 155: 245-253.

Yang F, Wang X, Liao D, Lu F, Gao R et al. (2015). Yield response to different planting geometries in maize–soybean relay strip intercropping systems. Agronomy Journal 107 (1): 296-304.

Yang F, Liao D, Fan Y, Gao R, Wu X et al. (2017). Effect of narrow-row planting patterns on crop competitive and economic advantage in maize–soybean relay strip intercropping system. Plant Production Science 20 (1): 1-11.

Yilmaz Ş, Atak M, Erayman M (2008). Identification of advantages of maize-legume intercropping over solitary cropping through competition indices in the East Mediterranean Region. Turkish Journal of Agriculture and Forestry 32 (2): 111-119.

Yu Y, Stomph TJ, Makowski D, van der Werf W (2015). Temporal niche differentiation increases the land equivalent ratio of annual intercrops: a meta-analysis. Field Crops Research 184: 133-144.

Zhang G, Yang Z, Dong S (2011). Interspecific competitiveness affects the total biomass yield in an alfalfa and corn intercropping system. Field Crops Research 124 (1): 66-73.