Moroccan Journal of Agricultural Sciences
Vol 3 No 1 (2022): (March 2022), 39-48
Crop Production and Environment

Response of sesame to intercropping with maize under different sowing dates and plant distributions of sesame

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Intercropping is one way to reduce the request for more environmental resources for agriculture sustainability. A field trail was implemented at Sids Agricultural Experimental and Research Station, Egypt, during 2019 and 2020 season to study the effect of sesame sowing date [3 weeks before sowing maize (D1), simultaneously with maize (D2) and 3 weeks after sowing maize (D3)] and plant distribution of sesame [1 row (S1), 2 rows (S2) and 3 rows (S3)] on yields of both crops, land use and financial benefit. Split-plot design with three replications was used. Results showed that the highest values of maize agronomic traits were observed when late intercropping of sesame at D3 with one row of sesame. In contrast, sowing 3 rows of sesame significantly reduced the productivity of maize, while introducing sesame at D1 resulted in the highest values for sesame agronomic traits. The values of LER, RCC and AYL of D2 x S1 surpassed the other intercropping treatments. Aggressivity was (+) for sesame at D1 and D2 but it was (-) at D3. Furthermore, D2 x S1 surpassed the other intercropping treatments in total return (2297 US$), MAI 633 and increased return by 61.5 % over solid maize. It can be concluded that sesame simultaneously with maize by inter seeding one row of sesame spaced into maize maximize land use, income and food sustainability.

Keywords: Land Equivalent Ratio (LER), Relative crowding coefficient (RCC) Actual yield loss (AYL), total returns

INTRODUCTION

Sesame (Sesamum indicum L.) is an important oilseed crop and a significant economic crop in Africa. Its oil has a high commercial value due to its edible quality and medicinal value. Seeds contain 50-60% oil, which is highly stable against rancidity. However, the slow growth in the domestic production of oilseeds, due to the lack of area planted with oil crops, has not been able to keep pace with rising demand in Egypt, resulting in increased imports and high inflation rates. Intercropping oilseed crops with other crops can be used, as one of the most effective approach to expand the cultivated area of these crops, so narrowing the gap between production and consumption without requiring new land (Mourad and El-Mehy, 2021). Intercropping sesame with other crops increase oil production and land productivity per unit area (El-Karamity et al., 2020), maximizing land equivalent ratio, gross income and net income (Afe, 2017, Mandal and Chhetri, 2019), reducing crop failure risk (Ram, 2020). Additionally, maize and sesame are regarded as good companion crops, helping to reduced weeds (Ijoyah et al., 2015). So we suggested intercropping sesame with maize, where maize (Zea mays L.) is consider the first summer cereal crop in Egypt considering acreage and total production. It occupies nearly 2.7 million fad and produced 7.5 millon ton of grains (FAOSTAT, 2020).

Sesame agronomic traits responded significantly to climate change when the sowing date was changed (Salem, 2016). In the most fertile soils are allocated to intercropping sesame with maize two weeks after maize planting (Isaac et al., 2020). Mkamilo (2004) who found that intercropping maize and sesame at the same time caused 27% reductions in grain yield of maize, but it gave increasing in LER and total income. This reduction decreased with delayed inter-seeding times of sesame. On the other hand, sesame yield was significantly reduced due to delayed sowing, owing to a direct effect of sowing time and increased competitiveness of maize. Intercropping sesame with maize simultaneously might give a good sesame seed yield under newly sandy soil conditions (Badran, 2009). Kolawole et al. (2015) observed that the growth and yield of maize were not affected when the two crops were simultaneously planted but the yield of sesame, being a weak competitor, decreased, particularly, when introduced two weeks after maize. Competitive relations are strongly impact by relative sowing time of intercrops (Akanvou et al., 2002; Badran, 2009; Mourad and El-Mehy, 2021).

Plant distribution manipulates the microenvironments and could affect the growth, development, and yield due to the interception of available photosynthetic active radiation (Isaac et al., 2020). Optimal plant spacing ensures plants grow properly both above and below ground by dissimilar utilization of nutrients and solar radiation. (Khan et al., 2017). The spatial arrangement of sesame and sorghum significantly affected sesame productivity and LER values and 1:1 arrangement system was preferable (Dejen et al., 2019). The main objective of this study is to find an area for sesame cultivation by intercropping with maize under different plant distributions and planting dates of sesame as well as their impact on the productivity of both crops, competitive relationship and farmer return.

MATERIALS AND METHODS

Experimental field

In the growing season of 2019 and 2020, field study was carried out at Sids Agricultural Experiments and Research Station, Agricultural Research Center (ARC), Beni Sweif governorate (Lat. 29o 12’ N, Long. 31o 01’ E, 32 m a.s.l.), Egypt. Mechanical analysis of the soil (0–30 cm) revealed that the experimental soil had a clay texture, with sand (19.5%), silt (33.3%), and clay (47.5%). Chemical properties of the experimental soil (0 – 30 cm) were analyzed by Water and Soil Research Institute, A.R.C., which were 43.5, 11.8 and 232.5 ppm available nitrogen, phosphorus and potassium, respectively, 7.85 pH value and 1.24 % organic matter. Methods of mechanical and chemical analysis were described by Chapman and Pratt (1961). The meteorological data for the studied area as monthly interval means in two growing seasons is presented in table 1.

Table 1: Monthly meteorological data of the experimental site in 2019 and 2020 seasons

Month	Max. T (Calfen)	Wind speed	Relative Humidity	Rainfall	Max. T	Wind speed	Relative Humidity	Rainfall
	2019 season				2020 season			
May	293.69	2.56	33.19	0.201	293.24	2.57	41.93	0.497
June	301.02	3.01	21.07	0.645	299.01	3.97	31.38	0.257
July	303.69	4.09	29.80	0.209	302.00	4.02	28.92	0.095
August	304.19	4.17	31.23	0.030	303.70	4.50	31.54	0.139
September	303.97	3.63	32.32	0.027	303.93	4.17	33.18	0.022
October	300.95	4.39	40.97	0.047	303.26	4.39	37.52	0.086
November	298.30	3.12	42.85	6.603	299.14	3.81	44.57	0.364

. *Table 1: Monthly meteorological data of the experimental site in 2019 and 2020 seasons*

Experimental design and treatments

The experiment was set up as a split-plot design with 3 replications. The main plots were devoted to date of intercropping sesame with maize and sub plots were arranged for plant distribution of sesame. The sub-plot area consisting of 4 beds (1.4 m in width and 3 m in length), it was 16.8 m^2. Solid planting of maize and sesame implemented to estimate the competitive relationships, yield advantage and total income/ha. Experimental treatments were as follow.

Sowing dates of sesame intercropped with maize

• D1: twenty one days before sowing maize.

• D2: simultaneously with maize.

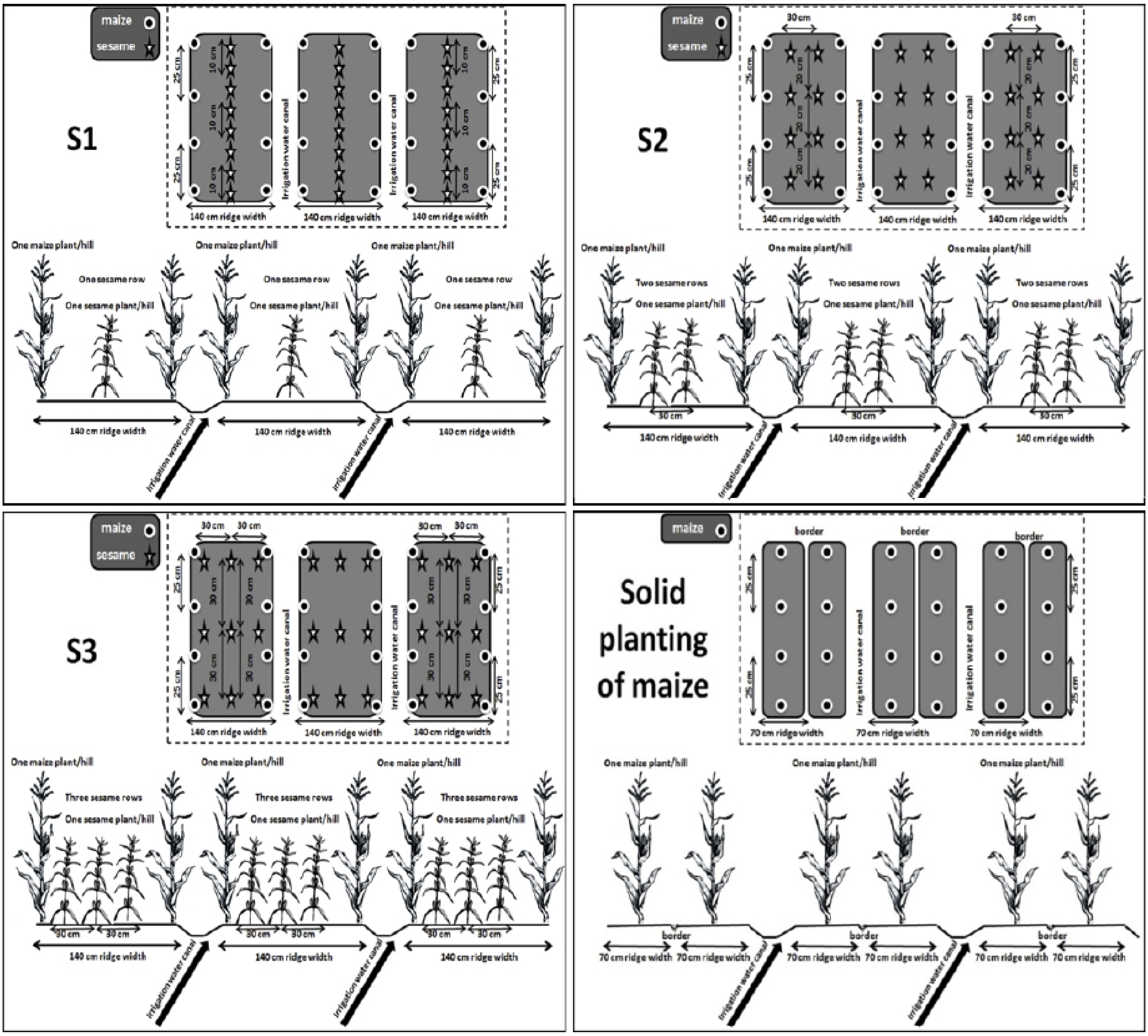
• D3: twenty one days after sowing maize.

Plant distribution of sesame intercropped with maize (Figure 1)

• S1: planting 1 row of sesame in the middle of the bed with left one plant/hill spaced at 10 cm between hills (71400 plants/ha).

• S2: planting 2 rows of sesame at 30 cm apart between rows, with left one plant/hill spaced at 20 cm between hills (71400 plants/ha).

• S3: planting 3 rows of sesame at 30 cm apart between rows with left one plant/hill spaced at 30 cm between hills (71400 plant/ha).



. *Figure 1: plant distribution of sesame intercropped with maize and solid maize*

Crop management

Maize cv. SC 176 (yellow corn) and sesame cv. Shandaweel-3 were used in this study. Maize seeds were planted on May 27th and 17th in 2019 and 2020 season, respectively, in either sole or intercropping system. Sesame sowing date were May 6th, 27th and June 16th in 2019 and on April 26th, May 17th and June 7th in 2020 season. Maize was planted on both sides of the bed with one plant/hill at spaced 25 cm between hills. Meanwhile, Sesame was planted on the top of the bed in 1, 2 and 3 rows at 10, 20 and 30 cm apart between hills, respectively. Plant density of all intercropping treatment was 100: 50 % maize with sesame of the sole planting. In the sole planting, maize seeds were sown on one side of the ridge at spacing of 70 cm with left one plant/hill at 25 apart (57120 plants/ha), while sole sesame was planted on ridge at 70 cm apart with one plant/hill at 10 cm apart (142800 plants/ha). All cultural practices were applied as recommended for the maize and sesame.

Data collected

Growth and yields of both crops

From each plot 10 plants were randomly selected at harvesting time, to determined growth and yield components for both crops. While the yield was estimated from the whole plot (kg) and then converted to ton/ha.

Maize: plant height (cm), ear length and diameter (cm), number of grains/row, ear weight (g), 100-grain weight (g) and grain yield (ton/ha).

Sesame: plant height (cm), number of capsules/plant, capsule length (cm), 1000- seed weight (g), seed yield/plant (g) and seed yield (ton /ha).

Competitive relationships

Land equivalent ratio (LER) is the most widely used index for evaluating intercrop performance by calculating the total land area needed under sole cropping to produce the yields obtained by an intercrop (Mead and Willey, 1980) as follows:

Where, Yaa and Ybb are the sole crop yield of a (maize) and b (sesame), while Yab and Yba are the intercrop yields of crop a and b, respectively.

Aggressivity (A): It mean a comparison of how much relative yield increase for the intercropped crop (a) on crop (b) with the expected crop to find out which of the two crops dominated in yield according to Mc-Gilchrist, (1965).

Where: Zab and Zba = the area ratio of the crop a (maize) and b (sesame) when intercropping.

For any other situations both crop will have the same numerical value but, the high of the dominant crop is positive and the dominated is negative. The greater numerical value of (Agg), gave greater difference in competitive abilities and hence the larger difference between actual and expected yield.

Relative crowding coefficient (RCC) K: It was estimated by multiplying the coefficient for maize (Kab) by the coefficient of the sesame crop (Kba) by De-Wit (1960):

Actual yield loss (AYL): The AYL is the proportionate yield loss of intercrops compared to sole crop as confirm by Banik (1996). The AYL was calculated as:

Where:

Farmer's financial

Total return

Total return of intercropping culture = Price of maize x yield + price of sesame x yield.

The average prices of maize and sesame were 214 and 1208 US$ per ton, respectively, to calculate the total return. The market price was used to display the average price of both crops.

Monetary advantage index (MAI)

Monetary advantage values were calculated based on gross returns as suggested by Willey (1979):

Statistical Analysis

Data were analyzed by analysis of variance (ANOVA) using MSTAT-C package (Freed, 1991). The least significant differences (LSD) test and Duncan's Multiple Range (DMR) test were used to compare mean values at a 5% level of probability.

RESULTS AND DISCUSSION

Effect of sesame sowing date on maize

Date of intercropping sesame into a maize crop (D) had a significant effect on all maize agronomic traits except ear diameter in two seasons (Tables 2 and 3). Intercropping sesame before the maize sowing by 3 weeks (D1) had a negative effect on maize agronomic traits, followed by intercropping of sesame simultaneously with maize (D2) compared to intercropping of sesame at 3 weeks after maize sowing (D3). The reduction of maize yields in intercropping culture with early intercropping of sesame have been attributed to competition degree and shading of sesame. In other mean, maize in intercropping system performed better when delaying sesame sowing 3 weeks. Delayed inter-seeding of sesame into maize at D2 and D3 resulted in a gradual increased in plant height by 9.57 and 8.13%, ear leaf area by 11.3 and 15.8%, ear weight by 12.4 and 18.6 %, ear length by 14.3 and 25.1%, No. grains/ row by 6.02 and 15.5%, 100-grain weight by 11.8 and 14.9% and grain yield per ha by 26.7 and 33.9% as compared to D1, as average of both seasons. This may be due to the decreased competitiveness of sesame which played a significant role in improving maize agronomic traits. Obviously, the earlier sown crop had an advantage in the establishment and competition for the available resources before the later crop was introduced into the combination. These results were accordance with Mkamilo (2004) who found that sowing maize and sesame at the same time significantly reduced plant height, cob length and grain yield of maize compared to intercropped sesame at four weeks later maize sowing. Sherif et al. (2005) they reported that delaying sowing date of maize 35 days after groundnut sowing resulted in substantial reduction in yield and its attributes of maize. As the sowing date of cowpea became more distant from that of the sesame, the yield of the sesame increased and yield of the cowpea reduced (Araújo, et al., 2013). On the other hand, Kolawole et al. (2015) observed that the growth and yield of maize were not affected when the two crops were simultaneously planted. The currently results are similar to those reported by Taylor (1986) early sowing date of sesame caused a reduction in sorghum yield, this reduction declined with sesame planting was delayed.

Table 2: Effect of sowing date, plant distribution of sesame and their interaction on maize traits of in both seasons

Trait / Treatment		Plant height (cm)			Ear leaf area (cm^2)			Ear weight (g)			Ear length (cm)		
		2019	**2020**	**Mean**	**2019**	**2020**	**Mean**	**2019**	**2020**	**Mean**	**2019**	**2020**	**Mean**
Sowing date of sesame (D)													
D1		197.9b	203.2b	200.6	558.9c	571.9c	565.4	148.3c	151.1c	149.7	16.44c	16.74c	16.59
D2		221.9a	217.7a	219.8	622.8b	635.9b	629.4	167.4b	169.2b	168.3	18.80b	19.11b	18.96
D3		213.6 ab	220.2a	216.9	655.4a	654.6a	655.0	179.7a	175.3a	177.5	20.51a	21.01a	20.76
$LSD_{0.05}$ D		**15.7**	**7.7**		**20.3**	**12.4**		**1.3**	**2.0**		**1.53**	**1.33**	
Plant distribution of sesame (S)													
S1		217.7a	215.8a	216.8	635.0a	633.8a	634.4	173.1a	173.3a	173.2	19.84a	20.28a	20.06
S2		209.9ab	213.0a	211.5	617.2b	627.9a	622.6	163.4b	165.6a	164.5	18.29b	18.82b	18.56
S3		206.1b	212.3a	209.2	584.9c	600.7b	592.8	159.0c	159.6a	159.3	17.62c	17.76c	17.69
$LSD_{0.05}$ S		**8.1**	**N.S**		**14.7**	**11.7**		**3.0**	**N.S**		**0.65**	**0.79**	
Solid maize		214.7	214.7	214.7	634.0	613.0	623.5	191.1	188.4	189.8	18.67	19.40	19.04
Interaction													
	S1	199.7c	202.3d	201.0	594.9a	581.3a	588.1	161.8d	165.7c	163.8	17.60a	17.87a	17.74
D1	**S2**	195.7c	201.7d	198.7	566.5a	587.1a	576.8	145.4e	151.3d	148.4	16.20a	16.47a	16.34
	S3	198.3c	205.7d	202.0	515.3a	547.2a	531.3	137.6f	145.1d	141.4	15.53a	15.87a	15.70
	S1	238.7a	224.3a	231.5	638.6a	653.9a	646.3	173.2c	175.3ab	174.3	19.60a	20.03a	19.82
D2	**S2**	216.3b	215.0c	215.7	630.2a	939.9a	785.1	165.4d	169.3bc	167.4	18.60a	19.23a	18.92
	S3	210.7b	213.7bc	212.2	599.6a	613.9a	606.8	163.7d	163.1c	163.4	18.20a	18.07a	18.14
	S1	213.7b	220.7a	217.2	671.5a	666.2a	668.9	184.3a	179.0a	181.7	22.33a	22.93a	22.63
D3	**S2**	217.7b	222.3a	220.0	654.9a	656.6a	655.8	179.3b	176.3ab	177.8	20.07a	20.77a	20.42
	S3	209.3bc	217.7	213.5	640.0a	640.9a	640.5	175.6c	170.5b	173.1	19.13a	19.33a	19.23
$LSD_{0.05}$ DxS		**14.1**	**5.33**		**N.S**	**N.S**		**3.05**	**6.39**		**N.S**	**N.S**	
Mean		211.1	213.7	212.4	612.4	620.8	616.6	165.1	168.2	166.7	18.59	18.95	18.77

Values followed by the same letters within a column are not significantly different according DMR test at $P < 0.05$.

. *Table 2: Effect of sowing date, plant distribution of sesame and their interaction on maize traits of in both seasons*

Table 3: Effect of sowing date, plant distribution of sesame and their interaction on maize traits in both seasons

Trait / Treatment		Ear diameter (cm)			No. of grains/row (No.)			100-grain wt. (g)			Grain yield (T/ha)		
		2019	2020	Mean	2019	2020	Mean	2019	2020	Mean	2019	2020	Mean
Sowing date of sesame (D)													
D1		4.40a	4.33a	4.37	35.96c	36.09c	36.03	26.63b	27.84c	27.24	4.22c	4.40c	4.31
D2		4.44a	4.40a	4.42	38.20bc	38.20bc	38.20	29.97a	30.94b	30.46	5.26b	5.66b	5.46
D3		4.49a	4.51a	4.50	41.29a	41.92a	41.61	30.66a	31.92a	31.29	5.46a	6.07a	5.77
LSD $_{0.05}$ D		**N.S**	**N.S**		**2.39**	**2.92**		**0.84**	**0.34**		**0.13**	**0.34**	
Plant distribution of sesame (S)													
S1		4.53a	4.49a	4.51	40.38a	40.32a	40.35	30.09a	31.28a	30.69	5.83a	5.39a	5.61
S2		4.47b	4.47a	4.47	38.80b	38.81b	38.81	29.38a	30.39b	29.89	5.43b	5.11b	5.27
S3		4.33c	4.28b	4.31	36.27c	37.08c	36.68	27.79b	29.03c	28.41	4.87c	4.44c	4.65
LSD $_{0.05}$ S		**0.04**	**0.12**		**0.12**	**1.47**		**0.72**	**0.19**		**0.13**	**0.23**	
Solid maize		4.44	4.40	4.42	39.60	38.20	38.90	33.22	33.95	33.59	6.36	6.93	6.65
Interaction													
	S1	4.47a	4.40a	4.44	38.80a	38.20a	38.50	27.48a	28.44a	27.96	4.66e	4.91d	4.78
D1	**S2**	4.40a	4.47a	4.44	36.27a	36.07a	36.17	27.28a	28.29a	27.79	4.41f	4.34e	4.38
	S3	4.33a	4.13a	4.23	32.80a	34.00a	33.40	25.13a	26.80a	25.97	3.58g	3.94f	3.76
	S1	4.53a	4.47a	4.50	39.47a	39.53a	39.50	30.74a	32.20a	31.47	5.64b	6.11b	5.88
D2	**S2**	4.47a	4.40a	4.44	38.93a	38.67a	38.80	30.70a	30.62a	30.66	5.36c	5.76c	5.56
	S3	4.33a	4.33a	4.33	36.20a	36.40a	36.30	28.48a	29.99a	29.24	4.77de	5.10d	4.93
	S1	4.60a	4.60a	4.60	42.87a	43.23a	43.05	32.05a	33.20a	32.63	5.87a	6.46a	6.17
D3	**S2**	4.53a	4.53a	4.53	41.20a	41.70a	41.45	30.17a	32.24a	31.21	5.55bc	6.18b	5.86
	S3	4.33a	4.40a	4.37	39.81a	40.83a	40.32	29.76a	30.31a	30.04	4.96d	5.57c	5.27
LSD $_{0.05}$ DxS		**N.S**	**N.S**		**N.S**	**N.S**		**N.S**	**N.S**		**0.22**	**0.19**	
Mean		4.44	4.42	4.43	38.48	38.73	38.61	29.09	30.23	29.66	4.98	5.37	5.18

Values followed by the same letters within a column are not significantly different according DMR test at $P < 0.05$.

. *Table 3: Effect of sowing date, plant distribution of sesame and their interaction on maize traits in both seasons*

Effect of distributions of sesame rows on maize

Distributions of sesame rows (S) into a maize crop had a significant effect on all maize agronomic traits except plant height in second season as shown in Tables 2 and 3. Intercropping three rows of sesame (S3) had a negative effect on maize agronomic traits, followed by two rows sesame (S2) as comparative to intercropping one row of sesame (S1) in both seasons. Inter-seed two and three rows of sesame into maize significantly decreased ear leaf area by 1.86 and 6.56 %, ear weight 5.02 and 8.02, ear length 7.48 and 11.81 %, ear diameter 0.89 and 4.43%, No. of grains/ear 3.82 and 9.10 %, 100-grain wt. 2.61 and 7.43 % and grain yield per ha 6.06 and 17.1 % compared to distribution sesame plants in one row, respectively, as average of the two seasons. The reduction of maize yield in intercropping culture with three rows intercropping of sesame have been attributed to the increased competitiveness of sesame, which played a significant role in decreasing maize agronomic traits, also, this may be the root of sesame is nearly of root of maize which increase competition between crops. Nonetheless, reducing the number of sesame rows intercropping with maize increased wide space between intercrop components, which increased solar radiation intercepted by both crops. These results were agreement with Alemayehu et al. (2017) who found that grain yield of maize from 1 row of common bean intercropped between 2 rows of maize higher than yield from 2 rows of common bean. Plant height, number of grains per cob, weight of grains, and yield of maize were influenced significantly by spatial arrangement with sesame (Isaac et al., 2020). In contrast, the response of sorghum grain yield to spatial arrangement with sesame was insignificant, despite a slight yield reduction in 2:2 sorghum: sesame arrangement compared to 1:1 or 2:1 arrangements (Dejen et al., 2019).

Also, results in tables 2 and 3 confirm that all maize traits in solid planting gave the highest values as compared with intercropping treatments. This might probably have resulted due to reduction in solar radiation owing to increasing plants populations per unit area under intercropping (100% maize + 50% sesame) than sole maize (100% maize), which subsequently resulted in decreased yield and its components of maize. The yield reduction of the intercropped maize could be caused by inter specific competition between both crops for light, carbon dioxide, water, nutrients. These results was agreement with Ajibola and Kolawole (2019) they noting that intercropping sesame with maize significantly decreased maize grain yield by 36% compared with the solid crop. Irrespective of the arrangement, the sole stand was superior in grain yield compared to the intercrops (Isaac et al., 2020).

Interaction effect between sowing date and distribution of sesame on maize

The dual interactive of sesame intercropping dates with distribution of sesame rows into a maize had no significant effect on maize agronomic traits, except plant height, ear weight, grain yield/plant and grain yield/ha (Tables 2 and 3). The highest maize plant height 239 and 224 cm was produced by inter-seeding one row of sesame at the same time of maize sowing. While, the highest values of ear weight (g) of 184 and 179 and grain yield/ha of 5.87 and 6.46 (ton) in mixture were observed when intercropping of sesame at 3 weeks after maize sowing with one row of sesame (Table 3). Moreover, sowing one row of sesame under all intercropping systems was effective in improving performance of maize agronomic traits and it indicated planting one row of sesame improved maize plants because decreasing competitiveness and shading under studied condition. In contrast, planting 3 rows of sesame under all sesame sowing dates significantly reduced the productivity of maize, followed by moderately decreased productivity when sesame were sown in two rows and slightly decreased productivity when sesame was introduced in one rows. A recent study conducted by Mkamilo (2004) and Isaac et al. (2020).

Effect of sesame sowing date on sesame

Sesame intercropping dates had a significant impact on agronomic traits of sesame (Tables 4 and 5). All sesame agronomic traits were significantly increased when sesame was planted in early date D1 (21 days before of maize planting). The increase in seed yield of sesame at early sowing D1 and D2 was 57.2 and 42.5 % per plant and 64.1 and 43.4% per ha compared to D3, respectively, as average of both seasons. It can be attributed to two reasons. Firstly, sesame agronomic traits responded significantly to climate change when the sowing date was changed. This may be due to severe climate conditions associated with high temperatures at late planting as shown in Table 1, where heat stress shortened the pre-flowering phase of plants that were planted later, consequently reduced No. of capsules/plant, seed weight/plant and seed yield Salem 2016). Secondly, intercropping sesame earlier than maize (D1) had a positive effect on sesame agronomic traits followed by intercropping of sesame simultaneously with maize (D2) owing to avoidance of shading effect. Where sesame plants were established and developed before maize plants become a competitor strongly for sesame plants. Intercropping advantage are usually better when the growth duration between the component crops varies widely than when the crops durations are similar (Yahuza 2011; Mourad and El-Mehy, 2021).

Table 4: Effect of sowing date, plant distribution of sesame and their interaction on sesame traits in both seasons

Trait / Treatment		Plant height (cm)			Branches/plant (No.)			Capsules/plant (No.)		
		2019	**2020**	**Mean**	**2019**	**2020**	**Mean**	**2019**	**2020**	**Mean**
Sowing date of sesame (D)										
D1		196.1a	215.0a	205.6	2.11a	2.44a	2.28	125.9a	141.7a	133.8
D2		182.2b	197.8b	190.0	2.00ab	1.78b	1.89	102.0a	127.8b	114.9
D3		140.0c	146.1c	143.1	1.56b	1.22c	1.39	89.2b	85.6c	87.4
$LSD_{0.05}$ D		**4.4**	**15.2**		**0.44**	**0.40**		**10.8**	**8.3**	
Plant distribution of sesame (S)										
S1		160.0c	175.0b	167.5	2.22a	2.22a	2.22	128.3a	143.3a	135.8
S2		171.1b	179.4b	175.3	1.78a	1.78a	1.78	103.9b	116.1b	110.0
S3		187.2a	204.4a	195.8	1.67a	1.44b	1.56	84.9c	95.6c	90.3
$LSD_{0.05}$ S		**7.4**	**9.8**		**N.S**	**0.64**		**6.2**	**6.1**	
Solid sesame		226.7	256.67		3.0	2.00		173.3	189.0	
Interaction										
	S1	185.0a	200.0a	192.5	2.67a	3.00a	2.84	150.0a	173.3a	161.7
D1	**S2**	190.0a	208.3a	199.2	2.00a	2.33a	2.17	120.0a	131.7c	125.9
	S3	213.3a	236.7a	225.0	1.67a	2.00a	1.84	107.7a	120.0de	113.9
	S1	173.3a	188.3a	180.8	2.33a	2.33a	2.33	126.7a	151.7b	139.2
D2	**S2**	183.3a	191.7a	187.5	1.67a	1.67a	1.67	98.0a	121.7cd	109.9
	S3	190.0a	213.3a	201.7	2.00a	1.33a	1.67	81.3a	110.0ef	95.7
	S1	121.7a	136.7a	129.2	1.67a	1.33a	1.50	108.3a	105.0fg	106.7
D3	**S2**	140.0a	138.3a	139.2	1.67a	1.33a	1.50	93.7a	95.0g	94.4
	S3	158.3a	163.3a	160.8	1.33a	1.00a	1.17	65.7a	56.7h	61.2
$LSD_{0.05}$ DxS		**N.S**	**N.S**		**N.S**	**N.S**		**N.S**	**10.6**	
Mean		172.8	186.3		1.89	1.81		105.7	118.3	

Values followed by the same letters within a column are not significantly different according DMR test at $P < 0.05$.

. *Table 4: Effect of sowing date, plant distribution of sesame and their interaction on sesame traits in both seasons*

Table 5: Effect of sowing date, plant distribution of sesame and their interaction on sesame traits in both seasons

Trait / Treatment	Capsule length (cm) 2019	Capsule length (cm) 2020	Capsule length (cm) Mean	1000-seed wt. (g) 2019	1000-seed wt. (g) 2020	1000-seed wt. (g) Mean	Seed yield/plant (g) 2019	Seed yield/plant (g) 2020	Seed yield/plant (g) Mean	Seed yield (T/ha) 2019	Seed yield (T/ha) 2020	Seed yield (T/ha) Mean
Sowing date of sesame (D)												
D1	3.00a	3.44a	3.22	4.15a	4.09a	4.12	22.80a	26.10a	24.45	0.84a	0.89a	0.87
D2	2.67ab	2.93b	2.80	3.86a	3.69ab	3.78	21.43a	22.88b	22.16	0.75b	0.77b	0.76
D3	2.33b	2.66b	2.50	3.25b	3.13b	3.19	14.90b	16.20c	15.55	0.52c	0.54c	0.53
$LSD_{0.05}$ D	**0.36**	**0.42**		**0.39**	**0.60**		**1.97**	**0.96**		**0.04**	**0.09**	
Plant distribution of sesame (S)												
S1	2.27b	3.64a	2.96	4.13a	4.06a	4.10	25.79a	27.49a	26.64	0.77a	0.81a	0.79
S2	2.59a	2.91b	2.75	3.69b	3.54b	3.62	19.17b	21.09b	20.13	0.72b	0.75b	0.74
S3	2.14b	2.48c	2.31	3.45b	3.31b	3.38	14.18c	16.60c	15.39	0.63c	0.65c	0.64
$LSD_{0.05}$ S	**0.26**	**0.24**		**0.35**	**0.27**		**1.18**	**1.64**		**0.05**	**0.06**	
Solid sesame	4.20	4.50	4.35	4.89	4.79	4.84	31.93	37.50	34.72	1.72	1.80	1.76
Interaction												
D1 S1	3.83a	4.17a	4.00	4.30a	4.72a	4.51	30.57a	31.77a	31.17	0.89a	0.95a	0.92
D1 S2	2.83a	3.33a	3.08	4.26a	3.92a	4.09	20.37d	25.10a	22.74	0.87a	0.93a	0.90
D1 S3	2.33a	2.83a	2.58	3.91a	3.65a	3.78	17.47d	21.43a	19.45	0.77b	0.80bc	0.79
D2 S1	3.17a	3.57a	3.37	4.27a	4.11a	4.19	28.13b	29.13a	28.63	0.85a	0.88ab	0.86
D2 S2	2.53a	2.83a	2.68	3.70a	3.53a	3.62	22.60c	22.33a	22.47	0.75b	0.76c	0.76
D2 S3	2.30a	2.40a	2.35	3.62a	3.43a	3.53	13.57e	17.17a	15.37	0.65c	0.67d	0.66
D3 S1	2.80a	3.20a	3.00	3.81a	3.37a	3.59	18.67d	21.57a	20.12	0.57d	0.59de	0.58
D3 S2	2.40a	2.57a	2.49	3.13a	3.18a	3.16	14.53e	15.83a	15.18	0.54d	0.56ef	0.55
D3 S3	1.80a	2.20a	2.00	2.81a	2.85a	2.83	11.51f	11.20a	11.36	0.46e	0.48f	0.47
$LSD_{0.05}$ DxS	**N.S**	**N.S**		**N.S**	**N.S**		**2.05**	**N.S**		**0.07**	**0.09**	
Mean	2.67	3.01	2.84	3.76	3.64	3.70	19.71	21.73	20.72	0.71	0.74	0.72

Values followed by the same letters within a column are not significantly different according DMR test at $P < 0.05$.

. *Table 5: Effect of sowing date, plant distribution of sesame and their interaction on sesame traits in both seasons*

However, delaying inter-seeding of sesame into maize at D2 and D3 resulted in a gradual decreased in plant height by 7.09 and 30.4%, number of branches/plant 17.1 and 39.0%, capsules number/plant by 16.6 and 40.8%, capsule length 13.0 and 22.4%, 1000-seed weight by 8.25 and 22.6%, seed weight per plant by 9.37 and 36.4 %, seed yield per ha by 12.6 and 39.1% compared to D1, respectively, as average of two season. Sesame intercropped 2 weeks after maize sowing was feeble, due to the shading effect of maize plants. This effect increased with time led to a decrease in photosynthetic activity and poor filling capsule. Similar effects were reported by other workers (Mkamilo 2004; Badran, 2009). Kolawole et al. (2015) who found that sesame sowing at the same time with maize and two weeks later maize decrease seed yield of sesame by 134 and 1392% respectively compared with sole sesame.

Effect of distributions of sesame rows on sesame

Plant distribution of sesame in rows into the maize had a significant impact on all sesame agronomic traits (Tables 4 and 5). Intercropping one row of sesame gave the highest values of sesame agronomic traits, followed by 2 rows of sesame, except plant height. Inter-seeding one (S1) and two rows (S2) of sesame with maize significantly increased No. of branches/ plant by 42.3 and 14.1%, No. of capsules/plant 50.4 and 21.8 %, 1000-seed weight by 21.3 and 7.1 %, seed yield/plant 73.1 and 30.0 % and seed yield/ha 23.4 and 15.6 % compared to three rows (S3), as average of both seasons. The highest increase in sesame yield has been attributed to the avoidance of shading and competition where, there were decreasing competitiveness with one row sesame while intercropping 3 row of sesame with maize increased intra and inter-specific competition between the two crops and the same crop, respectively, for basic growth resources. These findings are in line with those of (Mkamilo, 2004; Dejen et al. 2019). Opposite results confirmed by Badran (2009) all intercropping systems of alternating ridges of maize: sesame were statistically similar for sesame seed yield and its components.

It worth to noting that, all sesame traits in solid planting gave the highest values as compared with intercropping treatments (Tables 4 and 5). The reduction in yield of the intercropped sesame may be due to interspecific competition between the intercrop components for environmental resources and the aggressivity effects of maize. Results herein are in accordance with Badran (2009); Afe (2017) and Isaac et al. (2020).

Interaction effect between sowing date and distribution of sesame on sesame

In terms of sesame agronomic traits, the dual interaction between sesame intercropping dates and sesame distribution rows was insignificant except No. of capsules/plant and seed yield/plant in one season and seed yield/ha in two seasons (Tables 4 and 5). Early sowing date of sesame (D1) with plants distribution in one row (S1) resulted in the highest values for sesame agronomic traits. Thus, early inter-seeding date of sesame improved the competitiveness of sesame under the conditions of this research study. While, delayed inter-seeding of sesame into maize under all sesame distribution resulted in a significant decrease in sesame productivity. Simultaneous sowing of maize and sesame had a moderate impact, while sesame was introduced 3 weeks before maize sowing had a slight impact. A recent study conducted by Badran (2009) stated that intercropping sesame with maize by using the same ridge system and sowing both crops simultaneously in the same time might give a good sesame seed yield under newly sandy soil conditions. Mourad and El-Mehy (2021) found that sunflower sown at an early date simultaneously with sugar beet produced the highest seed yield and its components of sunflower, while sugar beet had the reverse trend.

Competitive relationships

Land equivalent ratio

Land equivalent ratio (LER) was used to compare the yields from sowing two crops together with yields from sowing the same crops in solid planting (Mead and Willey, 1980). Results in Table 6 showed clearly that the averaged values of LER ratios of sesame sowing dates x sesame distribution treatments were greater than 1.0 indicating that intercropping gave advantages in land use. Data also point out that the means of the relative yield of maize were ever higher than those of the relative yield of sesame, it confirm that maize more competitor than sesame these results in agreement with Kolawole et al. (2015), Ajibola and Kolawole (2019). LER of intercropping sesame in stimulatory maize planting by one row of sesame surpassed the other intercropping patterns in two seasons. It is obvious from the same table that planting one row of sesame and maize together increased relative yield of both crops and LER, which were 1.38 and 1.37 in two seasons respectively Meanwhile, the lowest LER values (1.01) were achieved by intercropping maize before sesame by 21 day, and sesame was distributed in 3 rows. These results are in harmony with those obtained by Akanvou et al. (2002) reported that relative sowing time had a significant effect on competitive relations. Simultaneous planting of sesame with maize achieved LER value higher than one, whereas intercropping at four weeks after maize sowing always resulted in LER values lower than one (Mkamilo, 2004). Spatial arrangement of sesame and sorghum significantly affected LER value (Dejen et al., 2019). Equivalent yields of maize were the highest for most of the intercropping treatments relative to sole maize with yield advantage of 14% from one row intercropping planting arrangement of common bean (Alemayehu et al., 2017).

Table 6: Effect of sowing date and plant distribution of sesame on land equivalent ratio (LER) and Aggressivity (A) in both seasons

Trait		Land equivalent ratio			Aggressivity		Land equivalent ratio			Aggressivity	
Treatment		RY m	RY s	LER	Ag m	Ag s	RY m	RY s	LER	Ag m	Ag s
		2019 season					2020 season				
D1	S1	0.73	0.52	1.25	-0.48	0.48	0.71	0.52	1.23	-0.54	0.54
	S2	0.69	0.50	1.19	-0.49	0.49	0.63	0.52	1.15	-0.63	0.63
	S3	0.56	0.45	1.01	-0.52	0.52	0.57	0.44	1.01	-0.50	0.50
D2	S1	0.89	0.49	1.38	-0.17	0.17	0.88	0.49	1.37	-0.16	0.16
	S2	0.84	0.44	1.28	-0.07	0.07	0.83	0.42	1.25	-0.04	0.04
	S3	0.75	0.38	1.13	-0.02	0.02	0.74	0.37	1.11	-0.02	0.02
D3	S1	0.92	0.33	1.25	0.38	-0.38	0.93	0.33	1.26	0.40	-0.40
	S2	0.87	0.32	1.19	0.34	-0.34	0.89	0.31	1.20	0.39	-0.39
	S3	0.78	0.27	1.05	0.36	-0.36	0.80	0.27	1.07	0.39	-0.39

. *Table 6: Effect of sowing date and plant distribution of sesame on land equivalent ratio (LER) and Aggressivity (A) in both seasons*

Aggressivity

The aggressivity is number revealed to competitive ability of the intercropping crops, if aggressivity values is (+) and the other is (-), this indicates the crop which gave (+) value, it have more competition ability. It is clear from the results in Table 6 aggressivity values of both crops differ by sesame sowing date varied, irrespective of plant distribution of sesame. Aggressivity values of maize were negative, whereas values of sesame were positive when synchronous planting (D2) and sowing sesame before maize by 3 weeks (D1). Opposite trend was detected with sowing sesame 3 weeks later maize (D3). These results could be due to competition degree among maize and sesame on nutrients, carbon dioxide, solar radiation and water, which indicate that maize and sesame are partially complementary in resource acquisition. Isaac et al. (2020) found that A values were negative for maize and positive for sesame regardless of the spatial arrangement. Contrary to the finding of Kolawole et al. (2015) who reported that maize has (+) sign and more competitive than sesame in a sesame/maize system. This discrepancy could be due to the sowing time of sesame and maize.

Relative crowding coefficient (RCC or K)

It is the measure of the relative dominance of one crop over another in the intercropping culture (De-Wit, 1960). There is a yield advantage of intercropping If K value is greater than one, but if the value of K is one there is no yield advantage on other hand if less than one the system has the disadvantage (Khan et al., 2017). Results in Table 7 clear that K values of all intercropping treatments were greater than one and ranged by 1.04 and 7.64 in 2019 season and 1.05 and 7.09 in 2020 season respectively. That means maize/sesame intercropping culture have yield advantage in both seasons. Generally, sowing sesame in the same time of maize or arrangement sesame plants into maize in one row have the highest K values. The Ks values of sesame exceeded those Km of maize with the early sowing date of sesame 3 weeks before maize (D1), indicating that sesame was a dominant component, whereas maize was the dominated. In contrast, maize was the dominant crop with simultaneous planting (D2) and delaying sesame sowing date 3 weeks after maize (D3). The highest values of K 7.64 and 7.09 were produced with one row sesame arrangement into maize under simultaneous planting (D2). On the other hand, the lowest values were produced by intercropping 3 rows of sesame in D3. These results indicated that the clear yield advantage owing to intercropping sesame with maize. Results were in accordance with those obtained by Donyavian et al (2018) who reported that planting one row of sesame in all cotton sowing date decreased intra and interspecific competition between two spices crops for basic growth resources, consequently formed suitable above and under-ground conditions for growth and development of both crops. Maize had K values higher than sesame, thus indicating its dominance in the intercropping system, where sesame was planted two weeks after maize (Ajibola and Kolawole, 2019).

Table 7: Effect of sowing date and plant distribution of sesame on relative crowding coefficient (RCC) and actual yield loss (AYL) in both seasons

Trait Treatment		RCC			AYL			RCC			AYL		
		K m	K s	K	AYL m	AYL s	Total AYL	K m	K s	K	AYL m	AYL s	Total AYL
		2019 season						2020 season					
D1	S1	1.34	2.20	2.96	0.09	0.58	0.67	1.20	2.25	2.70	0.06	0.59	0.65
	S2	1.11	2.06	2.28	0.03	0.53	0.56	0.83	2.18	1.81	-0.06	0.57	0.51
	S3	0.63	1.65	1.04	-0.16	0.36	0.20	0.65	1.62	1.05	-0.15	0.34	0.19
D2	S1	3.86	1.98	7.64	0.32	0.50	0.82	3.69	1.92	7.09	0.32	0.47	0.79
	S2	2.63	1.58	4.15	0.26	0.32	0.58	2.42	1.49	3.61	0.24	0.28	0.52
	S3	1.48	1.23	1.81	0.12	0.14	0.26	1.37	1.19	1.63	0.10	0.12	0.22
D3	S1	5.91	1.00	5.92	0.38	-0.01	0.37	6.87	0.99	6.80	0.39	-0.01	0.39
	S2	3.35	0.94	3.13	0.30	-0.04	0.26	4.06	0.91	3.71	0.33	-0.06	0.27
	S3	1.74	0.73	1.28	0.16	-0.19	-0.03	2.02	0.74	1.49	0.20	-0.19	0.01

. *Table 7: Effect of sowing date and plant distribution of sesame on relative crowding coefficient (RCC) and actual yield loss (AYL) in both seasons*

Actual yield loss (AYL)

It is clear from Table (7) actual yield loss (AYL) gave more precise information about the competition between intercrops over than the other indices. AYL values for maize were positive at all combinations of sowing date and plant distribution of sesame, except early sowing date of sesame 3 week before maize (D1) with 3 rows of sesame (in first season) and with 2 and 3 rows of sesame (in second season). In contrast, AYL values for sesame were negative with delaying intercropping sesame with maize (D3), irrespective sesame rows distribution. The highest value (0.82 and 0.79) of total AYL was recorded from intercropping one row of sesame into maize for simultaneous planting, while, the lowest value (-0.03 and 0.01) was observed from late sowing date of sesame (D3) with intercropping three rows of sesame with maize. This confirm that the earlier sown component had an initial advantage in establishing and competing for the available resources before the later crop was introduced in the mixture. These results of competition relationship and yield advantage are in agree with those obtained by Abou-Keriasha et al. (2011) who found that AYL of sorghum was negative when cowpea was intercropped three weeks before sorghum (D1) and was positive when synchronous planting (D2) and 3 weeks later sorghum (D3) were applied which indicates yield advantage for sorghum. Also, plant distribution of intercrop components is an important variable in the intercropping system that ensures plants grow properly both in their above and underground parts. Reduced number of wheat rows intercropped with sugar cane to one row over three increased total AYL (Ahmed et al., 2013).

Farmer’s financial: Total return and monetary advantage index (MAI)

The evaluation of different intercropping treatments was made for the two seasons as a total return and MAI. The results in Figure 2 showed that, all intercropping treatment gave financial advantage as compared to solid culture of maize. The results revealed that intercropping one row of sesame in the same date of maize planting surpassed the other intercropping patterns, it gave total return 2297 US$ and MAI being 633 as average in both seasons. On the other hand, the lowest values of gross return were produced by intercropping 3 rows at D3, it gave 1696 US$. While the lowest MAI 17 were produced by distribution sesame plant in 3 rows at D1. These results was accordance with Mkamilo (2004) and Ram (2020).

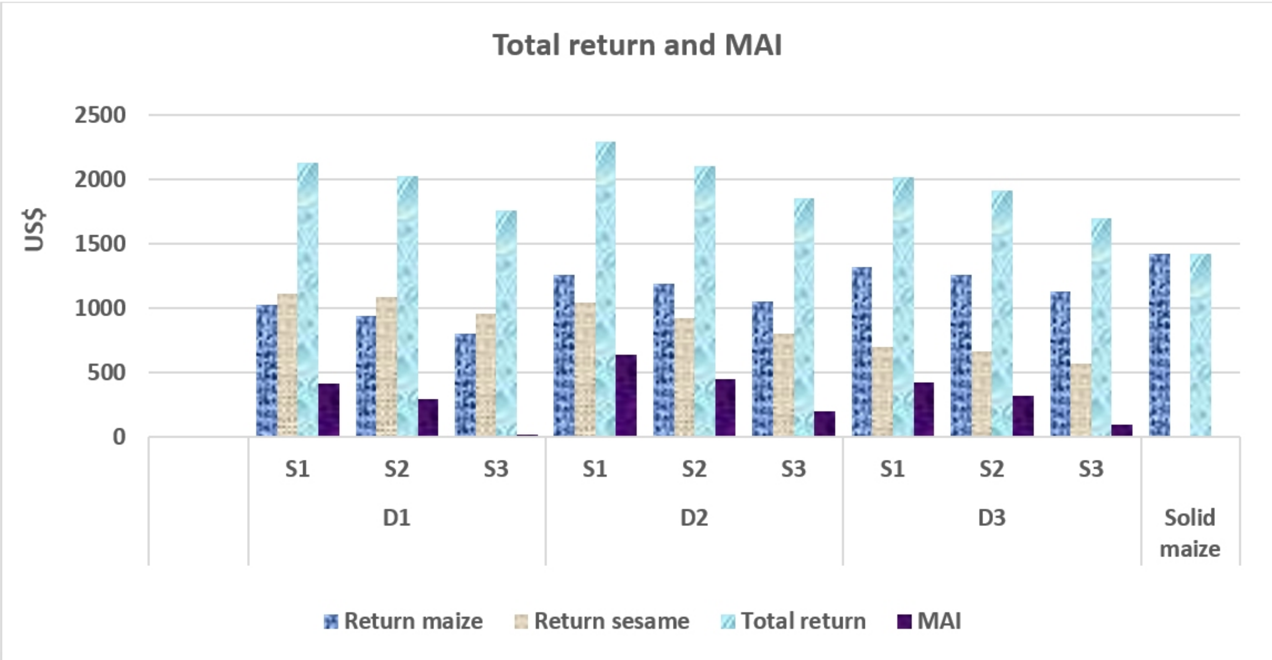


Figure 2: Effect of sowing date and plant distribution of sesame on total return and monetary advantage (MAI) index as average of both seasons

. *Figure 2: Effect of sowing date and plant distribution of sesame on total return and monetary advantage (MAI) index as average of both seasons*

CONCLUSION

In Egypt where maize is the number one summer cereal crop, planting sesame with maize can be feasible without adverse effects on maize yield. To find a place to produce sesame through the existing maize areas without entering into actual competition with summer crops and additional costs due to competition between summer crops (rice, maize and cotton). The best way to achieve this is to plant maize and sesame simultaneously. The average results over two seasons showed that sowing one row of sesame at the same time with maize achieve 0.86 ton sesame + 5.88 ton grain maize per ha compared to 6.65 ton per ha of sole maize, therefore increased total return by 61.5 % over sole maize. Also, this system saved land use by 38 % over sole planting of maize and reduced competition between to crops. Thus, it is recommended to sesame sowing simultaneously with maize by sowing one row of sesame in the middle of the maize bed (140 cm in width) with left one plant/hill spaced at 10 cm apart to increased oilseed crops production, land use efficiency and total return in Egypt.

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