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Augmenting Productivity and Profitability through Sesame with Sorghum Intercropping System

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A TWO-YEAR field trial was conducted at Shandaweel Research Station, Sohag Governorate, Egypt, during the 2021 and 2022 cropping seasons to study the effect of different plant distributions of sesame intercropped with some sorghum cultivars on the yield and yield components of both crops. The field experiment consisted of nine treatments, three sorghum cultivars (Dorado, Sohag-1 and Sohag-3), and three sesame plant distributions at 50, 33.3 and 25% of the recommended sole crop density of sesame, using a split-plot design with three replications. The results revealed that the highest yield in sorghum was obtained with 100% sorghum + 25% sesame and sorghum cultivar Sohag-3. On the other hand, the highest yield of sesame was obtained with 100% sorghum + 50% sesame and sorghum cultivar Dorado. The highest total land equivalent ratio (1.31) was recorded from 100% sorghum + 25% sesame with Dorado cultivar. The highest net return (2516 USD/ha) was obtained with 100% sorghum + 25% sesame and sorghum cultivar Sohag-3. It can be concluded from the study that the intercropping system of 100% sorghum + 25% sesame with cultivar Sohag-3 gave the highest productivity and economic return.

Keywords: Sesame plant distribution, Land saved, Sorghum cultivars, Land equivalent ratio, Net return.

Introduction

Multi-cropping in the form of intercropping systems has been a unique feature among smallholder farmers. Spatial arrangement, also known as crop geometry in cropping systems is one of the most important factors for higher yield. The benefits of intercropping may be especially important because these are achieved not by using costly inputs, but by the simple row arrangement of growing crops together (Kotadiya *et al.,* 2023). In Egypt, there is an increase in oil imports compared to oil production so, one of the best options to achieve the self-sufficiency in oils is to increase the cultivated area of oilseed crops. However, it is not immediately possible to expand the cultivated area under oilseeds in Egypt. However, such expansion in area could be possible by growing oilseeds as intercrops in some cereals and millets, like sorghum. This would help in reducing the gap between output and consumption without needing additional land by intercropping them with other crops (Mourad and El-Mehy 2021). The efficiency of intercropping systems relative to sole cropping were employed and indexes such as land equivalent ratio, competitive ratio, and intercropping advantage have been proposed to describe competition among the species and economic advantages of intercropping systems to explain intercropping systems' economic benefits and species competition (Ghosh, 2004; Baraki *et al.,* 2023). Grain sorghum (*Sorghum bicolor* L.) is a prominent cereal crop in Egypt, with an area of approximately 150,000 hectares dedicated to its cultivation. This produces an estimated yield of 780,000 tons (FAO, 2023). Notably, this crop demonstrates a remarkable capacity to thrive under conditions of biotic stress, such as elevated temperatures, drought, and salt stress. A significant proportion of the cultivated areas, approximately 70%, is concentrated in the Upper Egyptian region. An important oilseed crop and a major economic crop in Africa is sesame (*Sesamum indicum* L.). Its edible and therapeutic qualities give its oil a significant commercial worth. 50-60% of seeds are made of oil and protein (18-20%), which is quite resilient against rancidity (El-Mehy and Awad, 2022). El-Karamity *et al.,* (2020) stated that intercropping sesame with other crops increases oil production and land productivity per unit area. The intercropping systems maximize land equivalent ratio, increase income and reduce the risk of crop failure (Mandal and Chhetri, 2019; Ram, 2020). Dejen *et al.,* (2019) found that the spatial arrangement of sorghum and sesame significantly affected sesame productivity and land equivalent ratio values and 1:1 arrangement system was preferable. Therefore, this research was carried out to study the effect of different plant distributions of sesame intercropped with sorghum cultivars on the yield and yield components of both crops.

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Materials and methods

Description of the study area

Two field experiments were conducted at Shandaweel Research Station, Sohag Governorate, Upper Egypt (latitude of 26.33° N and longitude of 31.41° E) during 2021 and 2022 seasons. The soil of this experiment was clay as presented in Table 1.

Table 1. Some physical and chemical properties of experimental site in 2021 and 2022 seasons.

Properties	2021	2022
Mechanical analysis		
Sand (%)	19.85	18.90
Silty (%)	31.95	33.60
Clay (%)	48.20	47.50
Soil texture	clay	
Chemical analysis		
pH	7.56	7.76
Organic matter (%)	0.77	0.82
$CaCo_3$ (%)	1.80	1.75
EC (dS m^{-1})	0.92	0.87
Available N (mg/kg)	18.20	19.70
Available P (mg/kg)	11.00	13.40
Available K (mg/kg)	178.00	190.00

Experimental design and materials

The experiment was laid out in a randomized complete block designed in a split-plot arrangement using nine treatments as follow:

Main plots: Sorghum cultivars

1- Dorado
2- Sohag-1
3- Sohag-3

Sub-plots: Sesame plant distribution

Sesame was sown in one row in the middle of all beds (120 cm) in the intercropping plots as follows:

1- 10 cm planting distance: 100% sorghum + 50% sesame (83.300 plants ha^{-1}).
2- 15 cm planting distance: 100% sorghum + 33.3% sesame (55.533 plants ha^{-1}).
3- 20 cm planting distance: 100% sorghum + 25% sesame (41.650 plants ha^{-1}).

The recommended sole crop density of sesame 166.600 plants ha^{-1}. Sesame cv. Shandaweel 3.

Sowing methods and management practices

Sowing sorghum on beds (120 cm) growing two rows on both sides of all beds with two plants/hill at 20 cm apart in case of sole or intercropping, while sole sesame was sown on ridges width of 60 cm apart with one plant/hill at 10 cm apart (166.600 plants/ha). The experimental unit area was $10.8m^2$ consisted of three raised beds (300 cm long and 120 cm wide). Sole sorghum and sesame were used only for competitive relationships and economic evaluation. Sesame was planted on 15^{th} and 21^{st} May in 2021 and 2022 seasons, respectively, whereas sorghum was planted on 4^{th} and 10^{th} June in 2021 and 2022 seasons, respectively. Wheat was the preceding winter crop in the first and second seasons. Calcium super phosphate (15.5% P_2O_5) and potassium sulphate (48.8% K_2O) at the rate of 360 kg/ha and 120 kg/ha of were applied basally to supply phosphorus and potassium, respectively during the seed bed preparation. Nitrogen was applied in the form of ammonium nitrate (33.5% N) at the rate of 240 kg N/ha in two equal doses; the first dose, was used at the sowing and the second dose was added before the first irrigation for sole and intercropping sorghum with sesame. Furthermore, for sole and intercropping sesame, nitrogen was applied in the form of ammonium nitrate (33.5% N) at the rate of 71.4 kg N/ha in three equal doses; at 20, 35 and 50 days after sowing sesame. Sesame was harvested on 10^{th} and 12^{st} September in 2021 and 2022 seasons, respectively. Sorghum was harvested on 15^{th} and 18^{th} September in 2021 and 2022 seasons, respectively. For irrigation system, the controlled flood irrigation was used in this study during both seasons. The other normal recommended cultural practices for sorghum and sesame plants were employed as recommended by the Egyptian Ministry of Agriculture and Land Reclamation.

Data collection

At harvest: Ten guarded plants were taken randomly to measure yield and its components for sorghum and sesame plants:

Sorghum traits: plant height (cm), panicle length (cm), panicle width (cm), 1000-grain weight (g) and grain yield (kg/ha).

Sesame traits: plant height (cm), number of capsules/plant, seed weight/plant (g), 1000-seed weight (g), seed yield (kg/ha) and oil (%). Oil (%) was determined according to AOAC (2000) using Soxthelt apparatus.

Computation of competition indexes

1. **Land equivalent ratio (LER)**

$$LER = LER\ (sorghum) + LER\ (sesame)$$

LER was determined according to Willey (1979).

$$LER\ (sorghum) = \frac{Grain\ yield\ of\ intercropped\ sorghum}{Sole\ sorghum\ yield}$$

$$LER\ (sesame) = \frac{Seed\ yield\ of\ intercropped\ sesame}{Seed\ yield\ of\ sole\ sesame}$$

2. Land saved (LS%):

Land saved was calculated by Willey (1985)

$$LS\ (\%) = \left(\frac{LER - 1}{LER}\right) \times 100$$

Where land saved (%) > 0 there is advantage. On the other hand, land saved (%) < 0 there is disadvantage in terms of land used.

3. Competitive ratio (CR)

CR was calculated by **Willey and Rao (1980)**

$$CR\ (sorghum) = \left(\frac{LER\ (sorghum)}{LER\ (sesame)}\right) \times \left(\frac{Z2\ (sesame)}{Z1\ (sorghum)}\right)$$

$$CR\ (sesame) = \left(\frac{LER\ (sesame)}{LER\ (sorghum)}\right) \times \left(\frac{Z1\ (sorghum)}{Z2\ (sesame)}\right)$$

Where:

Z1 (sorghum) = sown proportion of crop sorghum (in sorghum intercropping with sesame).

Z2 (sesame) = sown proportion of crop sesame (in sesame intercropping with sorghum).

Economic evaluation

The farmer's benefit was evaluated in USD for gross return and net return according to the price of sorghum yield and price of sesame yield by Bulletin, (2022). The price of one kg of sorghum was USD 0.4 and price of one kg of sesame was USD 2.7.

$$Gross\ returns = Price\ of\ sorghum\ yield + Price\ of\ sesame\ yield$$

$$Net\ returns = Gross\ returns - Gross\ variable\ costs\ for\ (sorghum\ and\ sesame)$$

Statistical analysis

The Analysis of Variance (ANOVA) was carried out using statistical packages and procedures outlined by Gomez and Gomez (1984) using SAS program version 9.2 (2009). Mean separation was carried out using Least Significant Difference (LSD) at 5% level of significant.

Results and Discussion

1- Sorghum yield and its attributes

A- Effect of sorghum cultivars on yield and its attributes

The analysis of variance revealed that plant height, panicle length, panicle width, 1000-grain weight and grain yield of sorghum showed highly significant ($p < 0.05$) difference among the treatments. The highest plant height (173.02 and 170.48 cm) was recorded from the Sohag-1 cultivar while the lowest height (158.16 and 160.64 cm) was recorded with the Dorado cultivar in the first and second seasons, respectively (Table 2). The lowest thousand grain weight (30.07 and 25.91g) was recorded with the Dorado cultivar, while the highest values of thousand grain weight (35.22 and 32.67g) was recorded with the Sohag-3 cultivar in the first and second seasons, respectively. Sohag-3 cultivar had a more pronounced and positive effect on grain yield (6383.71 and 6169.20 kg/ha) as compared with sorghum Sohag-1 (6037.73 and 5813.89 kg/ha). On the other hand, Dorado cultivar recorded the lowest values (5352.92 and 5168.06 kg/ha), in 2021 and 2022 season, respectively. This may be attributed to the genetic potential of the sorghum cultivars interacting with environmental fundamental supplies during the vegetative and reproductive stages resulting in grain yield. These results were in agreement with those obtained by (Mourad *et al.,* 2022; Youssef *et al.,* 2024; Zarea *et al.,* 2024).

B- Effect of sesame plant distribution on yield and its attributes

The results in Table 3 showed that the plant distribution of sesame significantly affected sorghum yield and its components in two growing seasons. 100% sorghum + 50% sesame had the tallest plants (168.27 and 169.26 cm) in the first and second seasons, respectively. The lowest height plants were 162.91 and 162.37 cm in case of intercropping of 100% sorghum + 25% sesame in the first and second seasons, respectively. Those may be due to competition of associated crops for intercepting the light intensity compared with sole sorghum. These results were in agreement with Hamd-Alla *et al.,* (2014). On the other hand, intercropping of 100% sorghum + 25% sesame produced the maximum panicle length, panicle width, 1000-grain weight and grain yield as compared to intercropping of 100% sorghum + 50% sesame and 100% sorghum + 33.3% sesame in the first and second seasons. The maximum grain yield (6257.99 and 6029.23 kg/ha) was recorded for intercropping 100% sorghum + 25% sesame while the lowest grain yield (5648.16 and 5445.65 kg/ha) was recorded for 100% sorghum + 50% sesame in the 2021and 2022 seasons, respectively. These results could be attributed to the maximum values for the yield attributes in 100% sorghum + 25% sesame especially weight of panicle length, panicle width and 1000-grain weight. Further, this reduction in the yield attributes of sorghum under 100% sorghum + 50% sesame was ascribed to the highest plant density of sesame (sorghum intercropped with sesame at 20 cm between hills). In addition, plant distribution could affect growth, development, and yield due to the interception of available photosynthetic active radiation. Optimal plant spacing ensures plants grow properly both above and below ground by proper utilization of nutrients and solar radiation. Similar results were observed by (Khan *et al.,* 2017; Dejen *et al.,* 2019; Isaac *et al.,* 2020; El-Mehy and Awad 2022; Baraki *et al.,* 2023).

C- Interaction effect between sorghum cultivars and plant distribution of sesame

Plant distribution of sesame × sorghum cultivars interactions significantly affected on the sorghum traits, except plant height in first season. (Table 4). Decreasing sesame plant distribution from 50 to 25% of sole sesame with Sohag-3 cultivar increased grain yield/ha (6618.68 and 6386.00 kg/ha), compared to the others under intercropping system in the first and second seasons, respectively. On the contrary, increasing sesame plant distribution from 25 to 50% of sole sesame with Dorado cultivar decreased grain yield/ha (4960.20 and 4849.84 kg/ha) than the others under intercropping system in the first and second seasons, respectively. These results may be due to the canopy architecture of sorghum cultivar sohag-3 being more compatible with a decrease in sesame plant distribution per unit area from 50 to 25% of sole sesame to reduce intra and inter-specific competition between the same and different species, respectively for climatic and edaphic environmental conditions compared with the other treatments.

Table 2. Effect of sorghum cultivars on yield and its attributes of sorghum in 2021 and 2022 seasons.

Sorghum cultivars	Plant height (cm)		Panicle length (cm)		Panicle width (cm)		1000-grain weight (g)		Grain yield (kg/ha)	
	2021	2022	2021	2022	2021	2022	2021	2022	2021	2022
Dorado	158.16	160.64	29.05	29.33	5.57	5.48	30.07	25.91	5352.92	5168.06
Sohag-1	173.02	170.48	36.17	35.39	6.62	6.38	33.88	30.55	6037.73	5813.89
Sohag-3	166.32	166.91	33.27	31.17	6.42	5.98	35.22	32.67	6383.71	6169.20
LSD at 5%	0.48	0.76	0.31	0.08	0.07	0.06	0.11	0.16	27.65	10.03
Sole Dorado	155.35	155.00	33.91	31.72	6.62	6.05	33.00	28.81	5987.06	5728.36
Sole Sohag-1	168.70	168.30	37.80	37.42	7.73	7.35	35.92	34.00	6495.72	6165.49
Sole Sohag-3	161.54	160.00	35.24	34.45	7.80	7.50	37.19	36.20	6735.36	6592.40

Table 3. Effect of plant distribution of sesame on yield and its attributes of sorghum in 2021 and 2022 seasons.

Sesame plant distribution	Plant height (cm)		Panicle length (cm)		Panicle width (cm)		1000-grain weight (g)		Grain yield (kg/ha)	
	2021	2022	2021	2022	2021	2022	2021	2022	2021	2022
100% sorghum + 50% sesame	168.27	169.26	31.49	29.96	5.79	5.56	31.75	28.34	5648.16	5445.65
100% sorghum + 33.3% sesame	166.33	166.40	32.82	31.83	6.05	5.83	32.85	29.30	5868.21	5676.27
100% sorghum + 25% sesame	162.91	162.37	34.18	34.11	6.76	6.45	34.56	31.50	6257.99	6029.23
LSD at 5%	0.94	0.44	0.45	0.19	0.07	0.07	0.15	0.17	15.93	10.14

Table 4. Effect of the interaction between sorghum cultivars and plant distribution of sesame on sorghum during 2021 and 2022 seasons.

Treatment		Plant height (cm)		Panicle length (cm)		Panicle width (cm)		1000-grain weight (g)		Grain yield (kg/ha)	
		2021	2022	2021	2022	2021	2022	2021	2022	2021	2022
Sorghum cultivars	**Sesame plant distribution**										
Dorado	**100% sorghum + 50% sesame**	160.71	164.01	27.37	27.47	5.25	5.18	28.46	24.60	4960.20	4849.84
	100% sorghum + 33.3% sesame	158.74	160.84	28.92	29.05	5.48	5.37	29.84	25.17	5236.08	5038.41
	100% sorghum + 25% sesame	155.05	157.08	30.86	31.47	5.97	5.89	31.91	27.98	5862.48	5615.92
Sohag-1	**100% sorghum + 50% sesame**	175.18	172.64	35.41	33.85	6.26	5.95	32.71	28.89	5811.80	5553.10
	100% sorghum + 33.3% sesame	173.21	170.30	35.96	35.22	6.54	6.18	33.76	30.03	6008.60	5802.80
	100% sorghum + 25% sesame	170.67	168.50	37.13	37.11	7.05	7.01	35.16	32.75	6292.80	6085.76
Sohag-3	**100% sorghum + 50% sesame**	168.91	171.14	31.69	28.56	5.87	5.54	34.10	31.54	6172.48	5934.00
	100% sorghum + 33.3% sesame	167.05	168.06	33.57	31.20	6.12	5.95	34.95	32.69	6359.96	6187.60
	100% sorghum + 25% sesame	163.02	161.53	34.55	33.75	7.27	6.44	36.60	33.77	6618.68	6386.00
LSD at 5%		NS	1.32	0.53	0.14	0.12	0.10	0.18	0.27	47.89	17.37

2- Sesame yield and its attributes

A- Effect of sorghum cultivars on yield and its attributes

It is evident from Table 5 that plant height, number of capsules/plant, seed weight/plant, 1000-seed weight, seed yield and oil (%) of sesame were significantly affected by sorghum cultivars to sesame crop in both seasons. Dorado cultivar gave the highest values of sesame agronomic traits, followed by Sohag-3 cultivars, except plant height in Sohag-1. Sorghum cultivar Dorado and Sohag-3 with sesame significantly increased number of capsules/plant 141.76 and 138.00, seed weight/plant 31.16 and 29.38g, 1000-seed weight 3.68 and 3.57g, seed yield 250.57 and 227.39 kg/ha and oil (%) 43.67 and 42.98% compared to Sohag-1, as average of both seasons. The highest values in sesame yield under the sorghum cultivars Dorado and Sohag-3 compared to Sohag-1 have been attributed to Sohag-1 plants being found to be taller, more competitive, and more exposed to the sun. Thus, more shading and sesame suffered more as it was growing under the Sohag-1 canopy than Dorado and Sohag-3 sorghum cultivars in intercropping systems. The findings are in close agreement with those obtained by (Hamd-Alla and Singh 2019; El-Mehy and Awad 2022; El-Mehy *et al.,* 2023; Kotadiya *et al.,* 2023).

B- Effect of plant distribution of sesame on yield and its attributes

The results demonstrated in Table 6 revealed that, the plant distribution of sesame affected significantly in all studied traits in both seasons. 100% sorghum + 50% sesame had the tallest plants (202.02 and 192.33 cm) in the first and second seasons, respectively. Whereas, the lowest height of plants was 193.61 and 183.19 cm in case of intercropping of 100% sorghum + 25% sesame in the first and second seasons, respectively. On the other hand, intercropping of 100% sorghum + 25% sesame produced the maximum number of capsules/plant, seed weight/plant, 1000-seed weight and seed oil (%) as compared to intercropping of 100% sorghum + 50% sesame and 100% sorghum + 33.3% sesame in the first and second seasons. The maximum seed yield (287.97 and 241.74 kg/ha) was recorded for intercropping 100% sorghum + 50% sesame while the lowest seed yield (212.90 and 159. 80 kg/ha) was recorded for 100% sorghum + 25% sesame in the 2021and 2022 seasons, respectively. These results may be due to the plant distribution of sesame plants in the unit area which played a major role in sesame productivity per unit area under intercropping conditions. In addition, increased intraspecific competition between plants of sesame for staple growth resources such as solar radiation under intercropping 100% sorghum + 50% sesame more than intercropping of 100% sorghum + 25% sesame. The present reactions confirmed with those obtained by (Mohammed and Abd-El-Zaher 2013; Sheha *et al.,* 2017; El-Mehy *et al.,* 2018; Isaac *et al.,* 2020; Shehata and Hamd-Alla 2023).

C- Interaction effect between sorghum cultivars and plant distribution of sesame

The results show in Table 7 indicated that, the effect of interaction between plant distribution of sesame and sorghum cultivars was significantly affected seed yield and oil% in 2021 and 2022 seasons. In addition, plant height, number of capsules/plant and seed weight/plant were significantly in 2021 season only. On the other hand, 1000-seeds weight was significantly in 2022 season only. The highest seed yield of sesame (305.72 and 273.55 kg/ha) in 2021 and 2022 seasons, respectively was obtained under the intercropping of 100% sorghum + 50% sesame with Dorado cultivar. Whereas, the lowest mean value of seed yield of sesame was obtained with the intercropping of 100% sorghum + 25% sesame under Sohag-1 cultivar (182.42 and 137.80 kg/ha) in 2021 and 2022 seasons, respectively.

Table 5. Effect of sorghum cultivars on yield and its attributes of sesame in 2021 and 2022 seasons.

Sorghum cultivars	Plant height (cm)		Number of capsules/plant		Seed weight/plant (g)		1000-seed weight (g)		Seed yield (kg/ha)		Oil (%)	
	2021	2022	2021	2022	2021	2022	2021	2022	2021	2022	2021	2022
Dorado	192.57	183.19	140.44	143.07	32.66	29.66	3.79	3.57	275.97	225.16	43.55	43.79
Sohag-1	203.32	192.28	132.00	128.33	26.97	25.93	3.56	3.44	216.85	174.14	43.08	41.81
Sohag-3	197.70	189.08	137.22	138.78	29.56	29.19	3.57	3.56	252.42	202.35	43.06	42.89
LSD at 5%	0.92	2.23	0.66	0.84	0.22	1.38	0.06	0.05	4.06	4.51	0.04	0.12
Sole sesame	185.52	175.68	163.00	156.00	36.11	35.25	4.58	4.15	1054.85	940.08	45.33	46.10

Table 6. Effect of plant distribution of sesame on yield and its attributes of sesame in 2021 and 2022 seasons.

Sesame plant distribution	Plant height (cm)		Number of capsules/plant		Seed weight/plant (g)		1000-seed weight (g)		Seed yield (kg/ha)		Oil (%)	
	2021	2022	2021	2022	2021	2022	2021	2022	2021	2022	2021	2022
100% sorghum + 50% sesame	202.02	192.33	129.83	132.73	27.08	26.18	3.40	3.28	287.97	241.74	42.89	41.63
100% sorghum + 33.3% sesame	197.97	189.03	135.17	136.00	29.72	27.89	3.61	3.49	244.37	200.12	43.29	42.51
100% sorghum + 25% sesame	193.61	183.19	144.67	141.44	32.40	30.70	3.91	3.81	212.90	159.80	43.52	44.36
LSD at 5%	0.58	2.048	1.19	0.82	0.16	1.68	0.11	0.06	3.52	6.85	0.01	0.12
Sole sesame	185.52	175.68	163.00	156.00	36.11	35.25	4.58	4.15	1054.85	940.08	45.33	46.10

Table 7. Effect of the interaction between sorghum cultivars and plant distribution of sesame on sesame during 2021 and 2022 seasons.

Treatment		Plant height (cm)		Number of capsules/plant		Seed weight/plant (g)		1000-seed weight (g)		Seed yield (kg/ha)		Oil (%)	
		2021	2022	2021	2022	2021	2022	2021	2022	2021	2022	2021	2022
Sorghum cultivars	**Sesame plant distribution**												
Dorado	**100% sorghum + 50% sesame**	198.10	188.10	132.67	138.53	29.63	27.52	3.57	3.33	305.72	273.55	43.29	42.64
	100% sorghum + 33.3% sesame	192.81	183.23	138.67	142.00	32.86	29.59	3.78	3.45	284.51	216.66	43.59	43.50
	100% sorghum + 25% sesame	186.80	178.24	150.00	148.67	35.49	31.86	4.01	3.94	237.69	185.28	43.77	45.23
Sohag-1	**100% sorghum + 50% sesame**	206.10	196.05	126.33	124.67	24.69	24.52	3.30	3.22	265.80	205.41	42.65	40.50
	100% sorghum + 33.3% sesame	203.28	191.93	131.00	127.67	26.74	25.90	3.50	3.39	202.33	179.22	43.15	41.63
	100% sorghum + 25% sesame	200.58	188.87	138.67	132.67	29.47	27.36	3.88	3.71	182.42	137.80	43.44	43.31
Sohag-3	**100% sorghum + 50% sesame**	201.85	192.84	130.50	135.00	26.91	26.50	3.33	3.28	292.38	246.26	42.72	41.76
	100% sorghum + 33.3% sesame	197.80	191.93	135.83	138.33	29.55	28.18	3.55	3.63	246.28	204.46	43.12	42.38
	100% sorghum + 25% sesame	193.44	182.47	145.33	143.00	32.23	32.88	3.84	3.78	218.6	156.32	43.36	44.54
LSD at 5%		1.59	NS	1.15	NS	0.38	NS	NS	0.09	7.04	7.82	0.06	0.20

Computation of competition indexes

1. Land equivalent ratio

The land equivalent ratio (LER) is A vital indicator to measure the performance of intercropping systems. All the different combinations of intercropping systems studied were greater than unity (>1) demonstrating that intercropping improved land use Table 8. The relative yield of sorghum was higher than those of the relative yield of sesame, it demonstrates that sorghum is a more significant competitor to sesame. land equivalent ratio of 100% sorghum + 25% sesame with Dorado cultivar (1.31 and 1.30) exceeded the other intercropping systems in the first and second seasons, respectively. The lowest land equivalent ratio values (1.08 and 1.05) were achieved by 100% sorghum + 50% sesame and Sohag-1 cultivar in the first and second seasons, respectively. This indicates that intercropping sorghum with sesame was more productive than the sole culture of each crop. Dejen *et al.,* (2019) who found that intercropping system of sorghum and sesame significantly affected LER value. These results agree with those obtained by (Said and Hamd-Alla 2018; Hamada and Hamd-Alla 2019; El-Ghobashy *et al.,* 2020; El-Mehy and Awad 2022; Baraki *et al.,* 2023; Abd-Allah *et. al.,* 2025).

2. Land saved (%)

Regarding the land saved the highest land saved (23.56 %) gained from 100% sorghum + 25% sesame with Dorado cultivar in the first season. This means that it could cost about 0.235 ha if the monoculture system produced the same yield harvested from 1 ha by the intercropping system. In the other hand, the lowest land saved (4.55%) was obtained from 100% sorghum + 50% sesame with sohag-1 cultivar in the second season. In this study, this means that the land saved (%) was > 0 there is an advantage in terms of land used in all intercropping systems (Table 9). This is in line with the finding of (Hauggaard-Nielsen *et al.,* 2001; Baraki *et al.,* 2023).

3. Competitive ratio (CR)

The CR explains which one crop species is more competitive than others. Data presented in Table 10 indicated that the competitive ratio values for sorghum (dominant component) were generally greater than those of sesame (dominated component) and also sorghum cultivars of Sohag-1 and Sohag-3 greater than Dorado cultivar. The highest values of competitive ratio of sorghum obtained from 100% sorghum + 50% sesame with Sohag-3 cultivar (2.16) in the second season, while the lowest values were obtained from 100% sorghum + 25% sesame with Dorado cultivar (0.93) in the first season. This means that when sorghum intercropped with sesame, sorghum crop utilizes natural resources more aggressively than sesame crop. These results are in agreement with (Baraki *et al.,* 2023; Shehata and Hamd-Alla 2023).

Economic evaluation

The economic productivity of the effect of interaction between plant distribution of sesame and sorghum cultivars on the studied intercropping system of sorghum and sesame was performed for the gross return, gross variable costs and net return (USD/ha) of the two components (sorghum and sesame) and compared to sole sorghum. All intercropping systems gave financial advantage as compared to sole sorghum. The results in Table 11 showed that the economic evaluation was done to define if intercropping sorghum with sesame was profitable for farmers to adopt the application of this system. The 100% sorghum + 25% sesame and sorghum cultivar of Sohag-3 had the highest gross return (3103 USD/ha) and net return (2516 USD/ha) than the other treatments, followed by 100% sorghum + 33.3% sesame and sorghum cultivar of Sohag-3 (3071 and 2476 USD/ha) for gross return and net return, respectively as the average of both seasons. On the other hand, the lowest values of gross return and net return were found under 100% sorghum + 33.3% sesame with and sorghum cultivar of Dorado (2692 and 2097 USD/ha) for gross return and net return, respectively as the average of both seasons. These results are in accordance with (El-Mehy and Awad 2022; El-Mehy *et al.,* 2023; Hamd-Alla *et al.,* 2023; Kotadiya *et al.,* 2023; Mohamed and Bakheit 2025).

Table 8. Effect of the interaction between sorghum cultivars and plant distribution of sesame on land equivalent ratio (LER) during 2021 and 2022 seasons.

Sorghum cultivars	100% sorghum + 50% sesame						100% sorghum + 33.3% sesame						100% sorghum + 25% sesame					
	2021			2022			2021			2022			2021			2022		
	RY sorghum	RY sesame	LER	RY sorghum	RY sesame	LER	RY sorghum	RY sesame	LER	RY sorghum	RY sesame	LER	RY sorghum	RY sesame	LER	RY sorghum	RY sesame	LER
Dorado	0.83	0.29	1.12	0.85	0.29	1.14	0.97	0.25	1.22	0.97	0.22	1.19	1.03	0.28	1.31	1.04	0.26	1.30
Sohag-1	0.81	0.27	1.08	0.82	0.23	1.05	0.93	0.19	1.12	0.94	0.19	1.13	0.98	0.23	1.21	1.00	0.22	1.22
Sohag-3	0.87	0.23	1.10	0.85	0.20	1.05	0.93	0.17	1.11	0.92	0.15	1.07	0.98	0.21	1.19	0.97	0.17	1.13

Table 9. Effect of the interaction between sorghum cultivars and plant distribution of sesame on land saved (%) during 2021 and 2022 seasons.

Sorghum cultivars	100% sorghum + 50% sesame		100% sorghum + 33.3% sesame		100% sorghum + 25% sesame	
	2021	2022	2021	2022	2021	2022
Dorado	10.58	12.10	18.21	15.82	23.56	22.95
Sohag-1	7.05	4.55	10.46	11.65	17.53	18.11
Sohag-3	8.74	4.67	9.68	6.52	15.96	11.89

Table 10. Effect of the interaction between sorghum cultivars and plant distribution of sesame on competitive ratio (CR) during 2021 and 2022 seasons.

Sorghum cultivars	100% sorghum + 50% sesame				100% sorghum + 33.3% sesame				100% sorghum + 25% sesame			
	2021		2022		2021		2022		2021		2022	
	CR sorghum	CR sesame	CR sorghum	CR sesame	CR sorghum	CR sesame	CR sorghum	CR sesame	CR sorghum	CR sesame	CR sorghum	CR sesame
Dorado	1.43	0.70	1.45	0.69	1.28	0.78	1.48	0.68	0.93	1.08	0.99	1.01
Sohag-1	1.49	0.67	1.77	0.56	1.61	0.62	1.64	0.61	1.05	0.95	1.15	0.87
Sohag-3	1.93	0.52	2.16	0.46	1.80	0.56	2.10	0.48	1.19	0.84	1.46	0.69

Table 11. Effect of interaction between sorghum cultivars and sesame plant distribution on economic evaluation (USD/ha) as the average of both seasons.

Treatments		Gross return (USD/ha)	Gross variable cost (USD/ha)	Net return (USD/ha)
Sorghum cultivars	Sesame plant distribution			
Dorado	100% sorghum + 50% sesame	2707	610	2097
	100% sorghum + 33.3% sesame	2692	595	2097
	100% sorghum + 25% sesame	2824	587	2237
Sohag-1	100% sorghum + 50% sesame	2867	610	2257
	100% sorghum + 33.3% sesame	2834	595	2239
	100% sorghum + 25% sesame	2863	587	2276
Sohag-3	100% sorghum + 50% sesame	3059	610	2449
	100% sorghum + 33.3% sesame	3071	595	2476
	100% sorghum + 25% sesame	3103	587	2516
Sole sorghum	Dorado	2302	565	1737
	Sohag-1	2488	565	1923
	Sohag-3	2619	565	2054
Sole sesame		2606	536	2070

Conclusion

Based on the results of field of experiments, the highest yield in sorghum was obtained under 100% sorghum + 25% sesame and sorghum cultivar Sohag-3. On the other hand, the highest yield of sesame was obtained with 100% sorghum + 50% sesame and sorghum cultivar Dorado. The highest gross return (3103 USD/ha) and net return (2516 USD/ha) were obtained with 100% sorghum + 25% sesame intercropped sorghum cultivar Sohag-3.

Consent for publication
All authors declare their consent for publication.

Author contribution
The manuscript was edited and revised by all authors.

Conflicts of Interest
The author declares no conflict of interest.

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تعزيز الإنتاجية والربحية من خلال تحميل السمسم مع الذرة الرفيعة

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تم إجراء تجربة حقلية لمدة عامين في محطة بحوث شندويل بمحافظة سوهاج، مصر، خلال موسمي الزراعة ٢٠٢١ و٢٠٢٢ لدراسة تأثير توزيعات نباتية مختلفة من السمسم المحملة مع بعض أصناف الذرة الرفيعة على المحصول ومكوناته لكلا المحصولين. اشتملت التجربة الحقلية على تسع معاملات، موزعة على ثلاثة أصناف من الذرة الرفيعة (دورادو، سوهاج-١ وسوهاج-٣) وثلاث توزيعات لنباتات السمسم بنسب ٥٠، ٣٣,٣ و٢٥٪ من الكثافة الموصى بها للزراعة المنفردة للسمسم، باستخدام تصميم القطع المنشقة مرة واحدة مع ثلاث مكررات. أظهرت النتائج أن أعلى إنتاجية للذرة الرفيعة تم الحصول عليها من خلال تحميل ١٠٠٪ ذرة رفيعة + ٢٥٪ سمسم وصنف الذرة الرفيعة سوهاج-٣. من ناحية أخرى، تم الحصول على أعلى إنتاجية للسمسم من خلال تحميل ١٠٠٪ ذرة رفيعة + ٥٠٪ سمسم وصنف الذرة الرفيعة دورادو. تم تسجيل أعلى معدل كفاءة استغلال للأرض (١,٣١) عند تحميل ١٠٠٪ ذرة رفيعة + ٢٥٪ سمسم مع صنف دورادو. تم الحصول على أعلى صافي للعائد (٢٥١٦ دولار أمريكيا للهكتار) عند تحميل ١٠٠٪ ذرة رفيعة + ٢٥٪ سمسم وصنف الذرة الرفيعة سوهاج-٣. ويمكن الاستنتاج من الدراسة أن تحميل ١٠٠٪ ذرة رفيعة + ٢٥٪ سمسم مع صنف الذرة الرفيعة سوهاج-٣ أعطى أعلى إنتاجية وعائد اقتصادي.