Impact of different sesame intercropping dates with cotton on agronomic performance and insect pests infestation

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Abstract

Climate change has a negative impact on cotton and sesame yields. Intercropping can promote climate resilience through higher plant resources efficiency and natural suppression of insect pests, pathogens and weeds. A the two-year field trial was conducted to determine the best dates for intercropping sesame and cotton with respect to cotton and sesame agronomic performance and infestation by major pests. Sesame was planted two weeks before cotton, simultaneously with cotton, and two weeks after cotton into cotton planted on April 1, April 15 and May 1. Delayed intercropping of sesame increased cotton yield and yield-related traits at all cotton seeding dates and reduced infestations of insect pests, especially bollworms. Conversely, intercropping sesame two weeks before cotton was sown on May 1 produced the highest sesame agronomic trait values and decreased infestations of insect pests, including the sesame capsule borer. The highest land equivalent ratio (1.21) was obtained by intercropping sesame after two weeks with cotton planted on April 1. However, the lowest land equivalent ratio (1.0) was obtained by intercropping sesame two weeks before cotton in the cotton planted on April 15. On April 1, the relative crowding coefficient for intercropping treatments exhibited greater values than one, while April 15 displayed the lowest value. All of the intercropping treatments of sesame after cotton produced the best total return compared to the sole culture of cotton on the three dates. In summary, intercropping sesame after two weeks with cotton planted on April 1 was the best option for better cotton and sesame productivity, reduced pest pressure and higher economic returns.

Keywords: Cotton, Insect pests, Land equivalent ratio, Sesame, Total return

INTRODUCTION

Egyptian cotton (*Gossypium barbadense* L.) is one of the most important fiber and oil crops, and sesame (*Sesamum indicum* L.) is one of the most important crops in the Middle East and South Asia. Intercropping cotton and sesame provides a number of benefits, including increased labor efficiency, reduced risk of crop failure, more efficient land use, diversification of income and consumption, improved soil fertility, and weed control. Although sesame is a common ingredient in mixtures, it is considered secondary to cotton because cotton is intended to meet the basic fiber needs of the household. A cotton-sesame system is used to provide a high or near-high yield from the main crop (cotton) and an additional yield from sesame. Sesame is usually grown as an intercrop with cotton, but the best intercropping dates for sesame and cotton need further study.

If cotton and sesame are sown at the same time, the stronger competitiveness of sesame could lead to substantial yield losses in cotton (Donyavian *et al*., 2018). Thus, it is proven that early intercropping of a second crop reduces the production of a main crop. Intercropping sesame with cotton sown on April 1 had non-significant effects on all cotton traits at three sowing dates (April 15, April 30, and May 15) except seed yield/plant in the second season, which was significant, but seed yield/hectare was significant in both seasons (El-Shamy, *et al*. 2021). Intercropping sesame with cotton had negative effects on cotton seed yield and 100-seed weight, while sesame with cotton significantly increased oleic and linoleic acid content in cotton seed oil (Lamlom *et al*., 2020). Sunflower sown simultaneously with sugar beet on September 17 produced the highest seed yield and its components, while the opposite trend was observed for sugar beet (Mourad and El-Mehy., 2021). The studies mentioned in this section have shown that simultaneous sowing of cotton and sesame would result in significant yield losses.

Many pest species attack cotton and sesame plants in Egypt, causing economic harm in quantity and quality during the seedling, vegetative, and fruiting stages. Bollworms are the most destructive insects on cotton plants (Hafez *et al*., 1996; Al-shannaf, 1994, 2002 and 2010; Ibrahim, 2001 and 2006; Ibrahim *et al*., 2006; Ibrahim and Al-shannaf, 2017). Sesame plants are also susceptible to certain cotton pests, with the exception of bollworms. Plants may be forced to lose fruits and produce small bolls as a result of piercing-sucking insect infestations, while larger bolls may become soft and spongy and fail to mature (Chavan *et al*., 2010). Insect pests such as sesame webworm *(Antigastra catalaunalis)* is the most important insects that affect production of sesame.

Therefore, the main aim of this study was to determine the best sesame intercropping dates with cotton in terms of cotton and sesame agronomic performance, their gross financial returns and their pest infestation under certain cotton sowing dates.

MATERIALS AND METHODS

Site description

A field trial was conducted at Kafr-El-Hamam Agricultural Research Station, ARC, Zagazig, Sharkia Governorate, Egypt (latitude 30° 61' N, longitude 31° 50' E), during the 2018 and 2019 summer seasons. The soil texture of the experimental site was clay loam, and the soil characteristics are listed in table 1. Monthly mean meteorological data for temperature, relative humidity and rainfall in 2018 and 2019 seasons are presented in figure 1.

Design and treatments

A split plot design in a randomized complete block design with three replicates was used, with sowing dates for cotton in the main plots and intercropping dates for sesame in the subplots. The sowing dates for cotton were April 1, April 15, and May 1, and the dates for intercropping sesame and cotton were as follows: 1. planting sesame 2 weeks before sowing cotton (2WBC), 2. Planting sesame simultaneously with cotton (SDC), 3. Planting sesame 2 weeks after sowing cotton (2 WAC).

Agricultural practices

The sub - plot area was 24.5 m^2 and consisted of 5 beds, each bed was 1.4 m wide and 3.5 m long. Both cotton and sesame were sown on the beds. The distances between plants within the bed were 30 cm for cotton and 10 cm for sesame. Cotton cv. Giza 94 and sesame cv. Shandaweel-3

Table 1: The physical and chemical analyses of the experimental soil

Item	2018	2019
	Soil Composition	
Sand (%)	15.8	17.2
Silt (%)	43.3	45.6
Clay (%)	40.9	37.1
Water table (m)	3.14	2.86
Soil texture	Clay loam	Clay loam
	Chemical properties	
Concentration of N (mg kg^{-1})	156	148
Concentration of P (mg kg^{-1})	8.19	9.48
Concentration of K (mg kg^{-1})	425	432
Electrical conductivity (ds/m)	1.35	1.95
pH	7.72	7.45

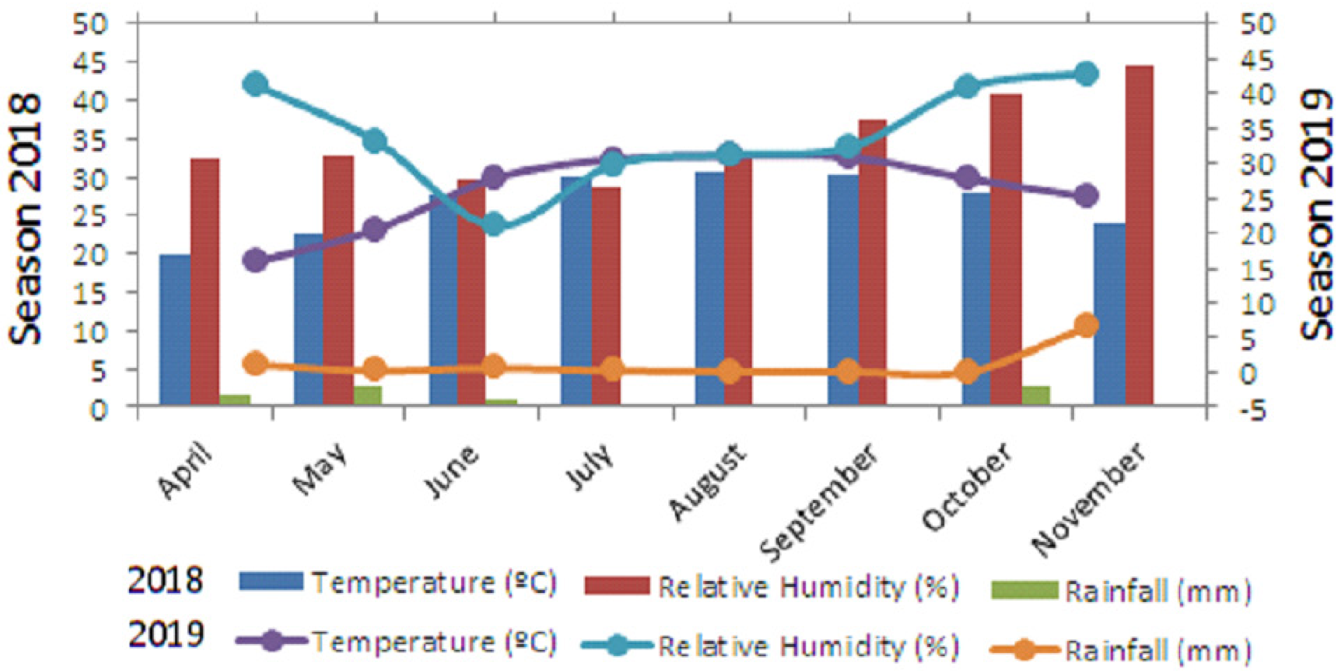

Figure 1: Monthly mean meteorological data for temperature, relative humidity and rainfall in 2018 and 2019 seasons

(Source: CLAC/ARC, Egypt)

were used in this study. Planting material for cotton was provided by the Cotton Research Institute and for sesame by the Oil Crop Research Department. Cotton was planted in the intercropping system at 100% density (on both sides of the bed), while sesame was planted at 50% density (in the middle bed) . Egyptian clover was the preceding winter crop in both years. At three weeks after sowing, plants of both crops were thinned to the desired density. The other agricultural practices, i.e. hoeing and irrigation, were applied as recommended.

Observations and measurements

Cotton and Sesame yield measurements

The final harvest for both sesame and cotton occurred at full maturity on September 1 and October 2 of the 2018 season and September 2 and October 4 of the 2019 season, respectively. For cotton, ten plants were randomly selected from each experimental unit for days to 50% flowering (day), plant height (cm), number of fruiting branches per plant (No.), first fruiting node (cm), boll weight (g), number of bolls (No.) per plant, lint percentage (%), seed index (g), lint index, and cotton seed yield per plant (g). Cotton seed yield, cotton lint yield, and seed yield were determined for each plot and converted to kentar/ hectare. Seed index = weight of 100 seeds. Lint index = (weight of lint/weight of seed) ×)seed index. For sesame, ten plants were randomly selected from each plot to determine days to 50% flowering (day), plant height (cm), fruiting zone length (cm), number of capsules per plant (No.), 1000-seed weight (g), and plant seed weight (g), while seed yield (kg/m^2) was determined from each plot and converted to hectare. Chemical composition of crude oil content was analyzed according to the methods of AOAC (1995) methods analyzed. Hence, sesame oil yield (kg/ hectare) was calculated by multiplying seed oil content (%) by seed yield (kg/hectare). Kentar of cotton seed yield= 157.5 kg.

Identifying the best date to intercrop cotton with sesame to achieve the highest yield and lowest susceptibility to pest infestation

Pest infestation measurement

To determine the best date to intercrop sesame and cotton, yield and percentage of pest infestation were compared with the economic component of the crop so that the grand mean, percentage of sesame capsules damage, and percentage of cotton bollworm infestation and their confidence intervals were calculated.

The percentage of cotton bollworm and sesame capsules borer (*Antigastra catalaunalis*) infestation was calculated using the following equation:

Cotton boll infestation (%) = (Total number of infested bolls/Total number of bolls) × 100

Sesame capsule damage% = (Total number of infested capsules/Total number of capsules) × 100

Confidence intervals were calculated using the following formula: Confidence interval = Grand mean ± $t_{0.05}$ value × standard error.

Competitive relationships

Land equivalent ratio (LER) is an index for evaluating the performance of intercrops by quantifying the total land area required for sole culture to produce the yields obtained with an intercrop (Mead and Willey, 1980), as follows:

$$LER= Yab/Yaa+ Yba/Ybb.$$

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

Aggressiveness (A): It means comparing the relative yield increase of the intercrop (a) on crop (b) with the expected crop to find out which of the two crops dominates in yield according to Mc-Gilchrist (1960), as follow:

$$Aab= Yab/(Yaa \times Zab)- Yba/(Ybb \times Zba)$$

Where: Zab = the area ratio of the crop (cotton in intercropping). Zba = the area ratio of the crop (sesame) in intercropping.

In all other situations, both crops have the same numerical value, but the high value of the dominant crop is positive and that of the dominated crop is negative. The higher the numerical value of aggressiveness, the greater the difference in competitiveness, and therefore the greater the difference between actual and expected yield.

Relative crowding coefficient (RCC) K: it is estimated by multiplying the coefficient for cotton (Kab) by the coefficient for the sesame crop (Kba) according to De wit (1960) as follows:

$$K=kab \times kba \quad kab= (Yab \times Zba)/((Yaa-Yab) \times Zab) \quad kba= (Yba \times Zab)/((Ybb-Yba) \times Zba).$$

Where: Zab = the area ratio of the crop (cotton) in intercropping. Zba = the area ratio of the crop (sesame) when intercropping.

Economic evaluation

The "economic" return to cotton farmers was calculated by determining the total return of intercropping compared to the recommended sole culture of cotton.

Total return/hectare. (L.E.) = (price of cotton seed yield × productivity) + (price of sesame seed yield × productivity)

Local prices were 2500 L.E. for cotton kentar and 20 L.E. for kg of sesame (market price in 2018 and 2019 seasons).

Statistical analysis

Analysis of variance according to Gomez and Gomez (1984) was calculated for all studied traits of cotton and sesame, as well as sesame capsule damage percentage and cotton bollworm infestation percentage using a split-plot arrangement in randomized complete block design. A combined analysis of variance was performed after confirming homogeneity of two seasons for all studied traits of cotton and sesame as well as sesame capsule damage percentage and cotton bollworm infestation percentage according to Hartley (1950). Mean of treatment effects was accomplished using the least significant difference (LSD) test and Duncan's Multiple Range Test at 5% level of probability to compare the means of the treatments.

RESULTS

Effect of cotton sowing dates on seed cotton yield and its components

Cotton agronomic traits responded highly significantly to changes in sowing dates (Table 2). Shifting the sowing date from April 1 to May 1 was associated with a highly significant decrease in all cotton agronomic traits, except for the first fruiting node. Shifting the sowing date to April 15 and May 1 resulted in a relative decrease in days to 50% flowering of 3.11% and 6.38%, respectively, compared to sowing on April 1.

Shifting the sowing date to April 15 and May 1 resulted in a gradual decrease in the main yield components, such as number of fruiting branches/plant by 15.4% and 33.1%, weight of bolls by 8.29% and 24.4%, number of bolls per plant by 6.87% and 23.8%, lint percentage by 6.97% and 23.7%, seed index by 8.92% and 21.3%, and lint index by 12.7% and 25.1%, respectively, compared to sowing on April 1. Yield-related traits had a positive influence on the expression of cotton seed yield per plant, cotton seed yield per hectare and cotton lint yield per hectare (Table 2). It was found that sowing on April 15 decreased the cotton seed yield per plant by 17.0%, corresponding to 20.8% on May 1 compared to sowing on April 1. In addition, delaying sowing on April 15 resulted in a decrease in cotton seed yield per hectare and lint cotton yield per hectare of 11.4% and 16.8%, respectively, while delaying sowing on May 1 resulted in a decrease of 29.9% and 29.3%, respectively, compared to sowing on April 1.

Effect of sesame intercropping dates on cotton seed yield and its components

Date of intercropping sesame with a cotton crop had a significant effect on all cotton agronomic traits (Table 3). Planting sesame 2 weeks before cotton sowing (2 WBC) had a negative effect on cotton agronomic traits, except for the first fruiting node, followed by planting sesame and cotton simultaneously (SDC) and planting sesame 2 weeks after cotton sowing (2 WAC) compared to a pure stand (CPS). On the other mean, cotton performed better in the intercropping system when sesame seed was delayed by 2 WAC. Delayed intercropping of sesame in cotton at SDC and 2 WAC resulted in a gradual increase in days to 50% flowering by 5.59% and 9.41%, plant height by 4.26% and 6.83%, number of fruiting branches/plant by 11.3 % and 22.5%, boll weight by 9.76% and 17.4%, boll number per plant by 14.5 % and 29.2%, lint% by 15.2 % and 32.5%, seed index by 20.0 % and 38.6%, lint index by 21.4% and 44.8%, seed cotton yield per plant by 3.79% and 10.4%, seed cotton yield kentar by 16.8% and 29.6%, and lint cotton yield per hectare by 21.5 % and 55.1%, respectively, compared with 2 WBC.

Effect of interaction between cotton sowing dates and sesame intercrop dates on cotton traits

The dual interaction of cotton sowing dates with sesame intercrop dates had a significant effect on cotton agronomic traits (Table 4). Sole culture gave the highest value compared to the intercropping treatment. The highest values

Table 2: Cotton seed yield and its components as affected by sowing dates of cotton (2018 and 2019 seasons)

Trait	Sowing date of cotton			LSD 5%
	April 1st	April 15th	May 1st	
Days to 50 % flowering	80.3 a	77.8 b	75.2 c	0.71
Plant height (cm)	163.4 a	158.3 b	151.6 c	1.90
Number of fruiting branches per plant	11.2 a	9.49 b	7.50 c	0.33
First fruiting node (cm)	11.5 c	13.6 b	16.5 a	0.50
Boll weight (g)	3.09 a	2.83 b	2.33 c	0.06
Boll number (N0)	38.2 a	35.6 b	29.1 c	0.92
Lint percentage (%)	33.7 a	31.3 b	25.7 c	0.65
Seed index	9.08 a	8.27 b	7.15 c	0.13
Lint index	5.99 a	5.23 b	4.49 c	0.08
Cotton seed yield per plant (g)	68.0 a	56.4 b	53.8 c	0.57
Cotton seed yield (kentar/ha)	22.0 a	19.5 b	15.4 c	0.21
Cotton lint yield (kentar/ha)	19.8 a	16.4 b	14.0 c	0.50

Table 3: Cotton seed yield and its components as affected by sesame intercropping (2018 and 2019 seasons)

Trait	Intercropping date of sesame			Sole culture	LSD 5%
	2 WBC	SDC	2 WAC		
Days to 50 % flowering	72.6 d	76.7 c	79.4 b	82.4 a	0.78
Plant height (cm)	149.6 d	155.9 c	159.8 b	165.8 a	1.51
Number of fruiting branches per plant	7.94 d	8.83 c	9.73 b	11.1 a	0.28
First fruiting node (cm)	18.2 a	15.2 b	12.7 c	9.49 d	0.54
Boll weight (g)	2.43 d	2.67 c	2.86 b	3.04 a	0.04
Boll number (N0)	27.8 d	31.9 c	36.0 b	41.7 a	0.88
Lint percentage (%)	24.2 d	27.9 c	32.1 b	36.7 a	0.68
Seed index	6.33 d	7.60 c	8.77 b	9.97 a	0.22
Lint index	3.93 d	4.77 c	5.69 b	6.56 a	0.09
Cotton seed yield per plant (g)	55.2 d	57.3 c	60.9 b	64.2 a	0.51
Cotton seed yield (kentar/ha)	15.7 d	18.3 c	20.3 b	21.6 a	0.19
Cotton lint yield (kentar/ha)	11.9 d	14.5 c	18.5 b	22.0 a	0.55

WBC, weeks before cotton sowing, WAC, weeks after cotton sowing, (SDC), simultaneously with cotton sowing. Kentar = 157.5 kg of cotton agronomic traits in the intercropping treatments were observed in the late intercropping of sesame 2 weeks after cotton sowing on April 1. In addition, late intercropping of sesame contributed to the improvement of cotton agronomic traits at all cotton sowing dates.

Effect of cotton sowing date on seed yield of sesame and its components

Sesame agronomic traits responded significantly to climate change when cotton sowing date was changed (Table 5). All sesame agronomic traits except days to 50% flowering were significantly increased when cotton sowing date was shifted from April 1 to May 1. Sowing on April 15 and May 1 resulted in a 7.52% and 16.6 % reduction in days to 50% flowering, respectively, compared to sowing on April 1. Plants that grew the highest were associated with a 2.67% delay in seeding date on April 15 and a 16.5 % delay on May 1 compared to early seeding on April 1. Compared with sowing on April 1, fruiting zone length increased by 10.7 % and 25.3 %, capsule number increased by 14.3 % and 44.4 %, and 1000-seed weight increased by 8.23% and 34.8% when sowing date was delayed until April 15 and May 1, respectively. Sesame yield per plant, sesame yield per hectare and seed oil content were positively affected by yield-related traits (Table 5). Sesame yield per plant increased by 14.8% on April 15 and 42.6% on May 1 compared to sowing on April 1. In addition, late sowing on April 15 resulted in an increase in sesame yield per hectare and seed oil content of 24.3 % and 9.83%, respectively, while late sowing on May 1 resulted in an increase of 51.9% and 18.3%, respectively, compared to sowing on April 1.

Effect of sesame intercropping date on seed yield of sesame and its components

The date of intercropping sesame had a significant effect on all agronomic traits of sesame (Table 6). All the traits of sesame were decreased in intercropping treatments compared to sole culture. Intercropping sesame 2 weeks

Table 4: Days to 50% flowering, plant height, number of fruiting branches per plant, first fruiting node, boll weight, and number of bolls as affected by interaction between cotton sowing dates and sesame intercropping dates (2018 and 2019 seasons)

Trait Interaction		Days to 50 % flowering (N)	Plant height (cm)	Number of fruiting branches per plant (N)	First fruiting node (cm)	Boll weight (g)	Boll number (N)
Cotton sowing dates	Sesame intercropping dates						
April 1st	2 WBC	75.5 ^{i}	156.5 ^{h}	10.2 ^{e}	15.1 ^{d}	2.76 ^{f}	31.6 ^{h}
	SDC	78.5 ^{f}	160.2 ^{d}	10.4 ^{d}	13.1 ^{g}	3.00 ^{d}	34.8 ^{f}
	2 WAC	82.0 ^{b}	164.5 ^{c}	11.7 ^{b}	10.7 ^{j}	3.17 ^{b}	39.0 ^{c}
	Sole culture	85.3 ^{a}	172.6 ^{a}	12.6 ^{a}	7.22 ^{l}	3.41 ^{a}	47.7 ^{a}
April 15th	2 WBC	73.8 ^{k}	151.7 ^{j}	8.38 ^{i}	17.7 ^{c}	2.60 ^{i}	30.0 ^{j}
	SDC	76.5 ^{h}	156.7 ^{g}	8.94 ^{h}	14.7 ^{f}	2.72 ^{g}	33.4 ^{g}
	2 WAC	79.0 ^{e}	159.8 ^{e}	9.57 ^{g}	12.3 ^{h}	2.92 ^{e}	37.6 ^{d}
	Sole culture	82.0 ^{b}	165.0 ^{b}	11.1 ^{c}	9.86 ^{k}	3.08 ^{c}	41.5 ^{b}
May 1st	2 WBC	68.5 ^{l}	140.5 ^{l}	5.28 ^{l}	21.8 ^{a}	1.93 ^{i}	21.9 ^{l}
	SDC	75.0 ^{j}	150.9 ^{k}	7.16 ^{k}	17.9 ^{b}	2.29 ^{k}	27.5 ^{k}
	2 WAC	77.3 ^{g}	155.1 ^{i}	7.92 ^{j}	15.0 ^{e}	2.47 ^{j}	31.3 ^{i}
	Sole culture	80.0 ^{d}	159.7 ^{f}	9.66 ^{f}	11.4 ^{i}	2.65 ^{h}	35.8 ^{e}
LSD 5%		1.35	2.61	0.49	0.94	0.07	1.52

WBC, weeks before cotton sowing, WAC, weeks after cotton sowing, (SDC), simultaneously with cotton sowing

Table 5: Sesame seed yield and its components as affected by sowing dates of cotton (2018 and 2019 seasons)

Trait	Sowing date of cotton			LSD 5%
	April 1st	April 15th	May 1st	
Days to 50 % flowering (N^0)	58.7 ^{a}	54.3 ^{b}	49.0 ^{c}	1.26
Plant height (cm)	138.0 ^{c}	141.7 ^{b}	160.8 ^{a}	1.89
Fruiting zone length (cm)	48.5 ^{c}	53.7 ^{b}	60.8 ^{a}	1.27
Capsule number (N^0)	71.0 ^{c}	81.1 ^{b}	102.5 ^{a}	2.46
1000-seed weight (g)	3.10^{c}	3.36 ^{b}	4.18 ^{a}	0.11
Seed weight per plant (g)	25.8 ^{c}	29.7 ^{b}	36.8 ^{a}	1.25
Seed yield (kg/ha)	515.6 ^{c}	641.0 ^{b}	783.1 ^{a}	12.6
Seed oil content (%)	46.2 ^{c}	50.8 ^{b}	54.7 ^{a}	0.60
Oil yield (kg/ha)	232.5 ^{c}	326.1 ^{b}	419.9 ^{a}	7.05

Table 6: Sesame seed yield and its components as influenced by sesame intercrop dates (2018 and 2019 seasons)

Trait	Intercropping date of sesame			Sole culture	LSD 5%
	2 WBC	SDC	2 WAC		
Days to 50 % flowering (N^0)	53.2 ^{c}	44.3 ^{d}	60.1 ^{a}	58.4 ^{b}	0.85
Plant height (cm)	141.9 ^{c}	117.2 ^{d}	166.6 ^{a}	161.6 ^{b}	2.10
Fruiting zone length (cm)	52.8 ^{c}	42.0 ^{d}	62.2 ^{a}	60.5 ^{b}	1.16
Capsule number (N^0)	80.7 ^{c}	63.4 ^{d}	99.7 ^{a}	95.7 ^{b}	2.66
1000-seed weight (g)	3.55 ^{c}	3.26 ^{d}	3.72 ^{a}	3.66 ^{b}	0.09
Seed weight per plant (g)	29.7 ^{c}	26.5 ^{d}	34.1 ^{a}	32.7 ^{b}	0.61
Seed yield per hectare (kg)	540.6 ^{b}	480.8 ^{c}	431.6 ^{d}	1133.3 ^{a}	9.31
Seed oil content (%)	51.3 ^{b}	54.2 ^{a}	48.0 ^{d}	48.9 ^{c}	0.53
Oil yield per hectare (kg)	268.0 ^{b}	249.4 ^{c}	237.3 ^{d}	480.8 ^{a}	6.74

WBC, weeks before cotton sowing, WAC, weeks after cotton sowing, (SDC), simultaneously with cotton sowing before cotton sowing (2 WBC) had a high positive effect on sesame agronomic traits, except seed oil content, followed by intercropping sesame simultaneously with cotton (SDC), intercropping sesame 2 weeks after cotton sowing (2 WAC) compared to sesame sowing on May 1 in the pure stand (SPS). In intercropping with early sesame sowing, the highest increase in sesame yields was attributed to avoidance of shading of cotton. As a result of delaying sesame sowing by 2 WAC, sesame production in intercropping systems declined dramatically. Delayed intercropping of sesame in cotton at SDC and 2 WAC resulted in a gradual decrease in days to 50% flowering by 8.85% and 24.2%, plant height by 12.2% and 27.5%, fruiting zone length by 12.8% and 30.6%, number of capsules by 15.7% and 33.7%, 1000-seed weight by 3.13% and 11.0%, seed weight per plant by 9.07% and 18.9%, seed yield per hectare by 11.07% and 20.2%, oil yield per hectare by 6.94% and 11.5%, while seed oil content increased by 4.81% and 10.8%, respectively, compared with 2 WBS.

Interaction effect between cotton sowing dates and sesame intercrop dates on sesame

For sesame agronomic traits, the dual interaction between cotton sowing dates and sesame intercropping dates was significant (Table 7). Sesame alone gave the highest value compared to the intercropping treatments. Intercropping sesame 2 weeks before cotton seeded on May 1 resulted in the highest sesame agronomic trait values. In addition, early intercropping of sesame improved sesame agronomic performance at all cotton sowing dates.

Effect of cotton sowing dates and sesame intercrop dates on pest infestation

The most harmful insects on cotton and sesame crops in monoculture and intercropping systems are cotton bollworm and sesame capsule borer (*Antigastra catalaunalis*).

A biplot of plant yield and infection percentage was created to select intercropping systems with low susceptibility to pest infestation and high yield per plant (Figure 2). Overall, the results showed that, compared to solid culture in cotton and sesame, intercropping sesame with cotton reduced bollworm infestation (%) of cotton and damage capsules borer (%) in sesame. Intercropping sesame 2 weeks after cotton seeding on April 1 had the highest cotton seed yield per plant with the lowest susceptibility to bollworm infestation (%), indicating that this was the more ideal date for cotton. On the other hand, intercropping sesame 2 weeks before cotton seeding on May 1 had the highest sesame seed weight per plant and the lowest susceptibility to sesame capsules borer damage (%), indicating that this was the more ideal timing for sesame.

Table 7: Days to 50 % flowering, plant height, fruiting zone length, capsule number and1000-seed weight as affected by interaction between cotton sowing dates and sesame intercropping dates (2018 and 2019 seasons)

Traits Interactions		Days to 50 % flowering (N^0)	Plant height (cm)	Fruiting zone length	Capsule number (N^0)	1000-seed weight (g)
Cotton sowing dates	**Sesame intercropping dates**					
April 1st	**2 WBC**	61.2 b	144.6 g	53.5 g	75.8 h	3.14 k
	SDC	56.5 e	130.5 i	46.6 i	68.5 j	3.15 j
	2 WAC	48.0 j	108.1 l	35.7 l	50.8 l	2.86 l
	Sole culture	69.2 a	168.8 c	58.4 d	88.8 e	3.27 h
April 15th	**2 WBC**	60.7 c	168.7 d	62.3 c	95.4 c	3.52 e
	SDC	54.7 f	148.5 e	54.6 f	81.4 f	3.40 f
	2 WAC	47.8 k	114.9 k	45.0 k	67.1 k	3.20 i
	Sole culture	54.0 g	134.6 h	53.0 h	80.7 g	3.32 g
May 1st	**2 WBC**	53.3 h	171.6 b	65.7 b	116.0 b	4.32 b
	SDC	48.5 i	146.8 f	57.1 e	92.2 d	4.09 c
	2 WAC	37.0 l	128.6 j	45.3 j	72.4 i	3.72 d
	Sole culture	57.0 d	196.3 a	75.3 a	129.5 a	4.59 a
LSD 5%		1.48	3.64	2.00	4.61	0.15

WBC, weeks before cotton sowing, WAC, weeks after cotton sowing, (SDC), simultaneously with cotton sowing

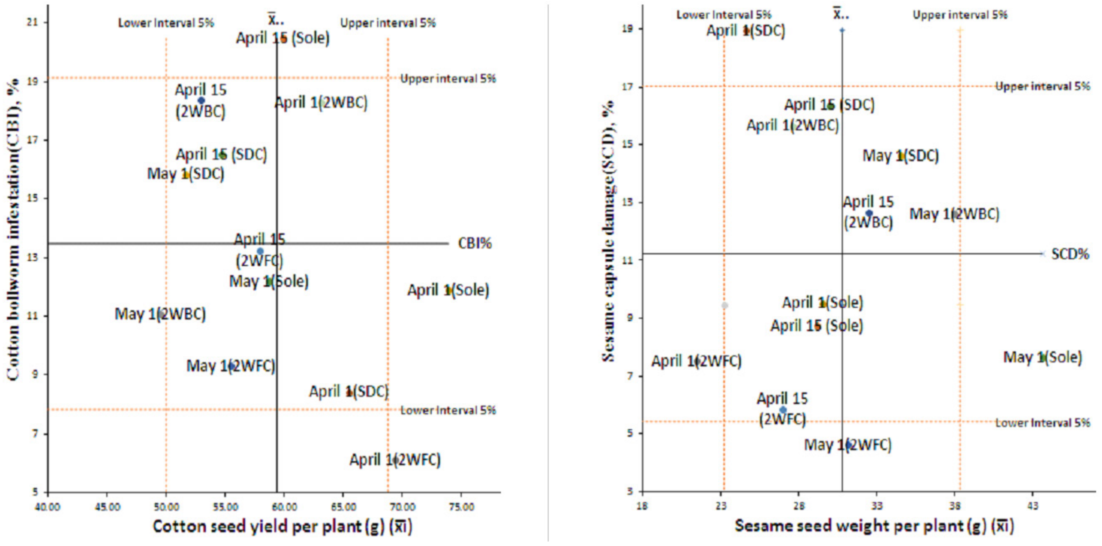

Figure 2: Biplot of yield per plant and pest infestation % for the intercropping system

Competitive relationship

Land equivalent ratio

The average values of LER ratios of treatments cotton sowing dates × sesame intercropping dates were greater than 1.0, indicating that intercropping provided land use benefits, implying that actual productivity was higher than expected (Figure 3A). The land equivalent ratio of intercropping sesame after 2 weeks with cotton planting on April 1 (2WAC) outperformed the other intercropping patterns in the combined analysis. From the same figure, it can be seen that because planting sesame 2 weeks after planting cotton increases the total relative yield of both crops and which caused increasing LER. The highest LER values (1.21) occurred when sesame was intercropped after 2 weeks and cotton was intercropped on April 1, it gave 1.21. The lowest LER values (1.0) were obtained by planting sesame 15 days before cotton, which was planted on April 15.

Aggressiveness

Aggressiveness number, if it reaches the value zero, it means that both crops have the same competitiveness, and the value of aggressiveness is the same for both crops, but one of the values is positive and the other is negative. The higher the value of aggressiveness, the greater the difference between the actual yield and the expected yield. Aggressiveness differed between crops based on the sowing dates of cotton and sesame in intercropping dates (Figure 3B). Aggressiveness was positive in some cotton treatments and negative in other treatments. Intercropping sesame 2 weeks after cotton seeding resulted in the highest aggressiveness; it was positive for cotton and negative for sesame. Planting cotton and sesame at the same date followed by planting sesame 2 weeks after the third cotton date resulted in the lowest aggressiveness value between cotton and sesame. Aggressiveness was positive for sesame and negative for cotton. On the first and second date of planting cotton, aggressiveness was positive for cotton, while intercropping sesame before cotton in the second date was negative. Aggressiveness was increased by delaying intercropping of sesame, but by the third planting date of cotton, aggressiveness was positive for sesame and aggressiveness was decreased by delaying intercropping of sesame.

Relative crowding coefficient (RCC)

The relative crowding coefficient (K) is greater than one and ranged from (1.13-10.38) in the combined analysis, which means that all intercropping treatments have a yield advantage (Figure 3C). The results of relative crowding coefficient (K) showed higher values than one for intercropping treatments on April 1 (2 WACS), while April 15 (2 WBCS) showed the lowest value. RCC value of planting after 2 weeks with cotton on April 1 exceeded the value for planting after 2 weeks. The RCC value of planting after 2 weeks with cotton planting on April 1 outperformed the other intercropping patterns in the combined analysis. The highest RCC values (10.38) occurred when sesame was intercropped after 2 weeks and cotton was planted on April 1. The lowest RCC values (1.13) were obtained by intercropping sesame 15 days before planting cotton on April 15.

Total return

The evaluation of the different intercropping treatments was made for the combined analysis as a total return. Total return differed by intercropping treatments (Figure 3D). All intercropping treatments of sesame after cotton produced higher total return than cotton alone on the three dates. The results showed that intercropping sesame after 2 weeks with cotton in 1st April outperformed

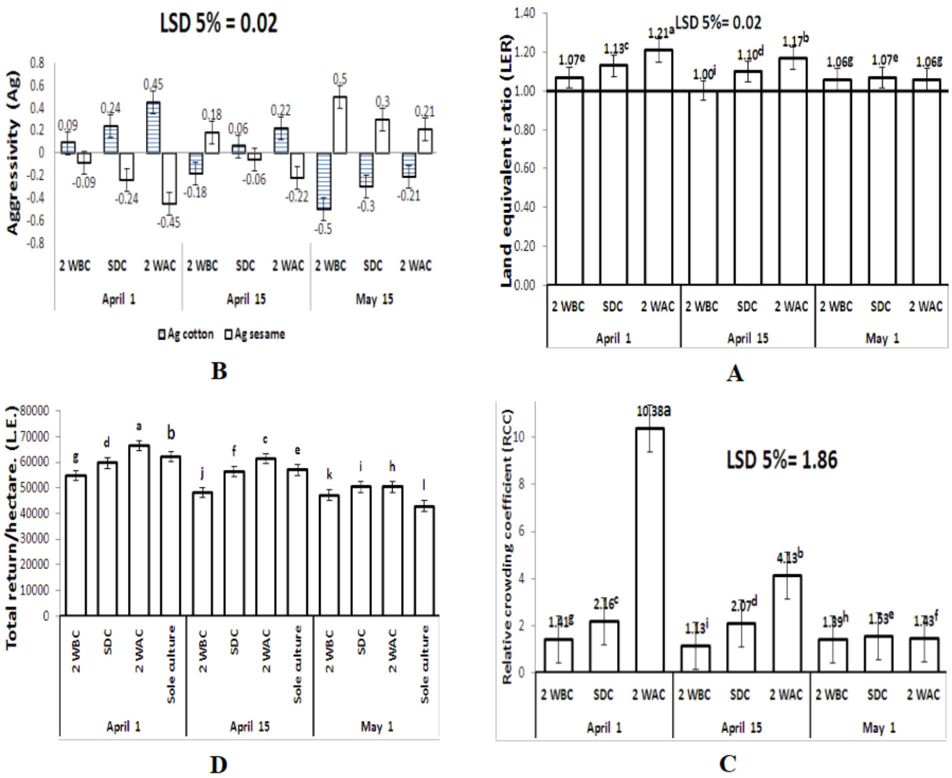

Figure 3: Effect of the interaction between cotton sowing dates and sesame intercropping dates on competitive relationship and total return (2018 and 2019 seasons)

the other intercropping patterns, it yielded 66498 L.E./hectare in the combined analysis. On the other hand, the lowest values of gross yield were obtained by the intercropping of sesame before cotton on the third date of cotton, it yielded 47161 L.E./hectare. The greatest benefit of intercropping was the increase of farmers' profits. Intercropping sesame before cotton or at the same time as cotton on the first and second cotton dates alone reduced the total yield compared to sole culture.

DISCUSSION

Changes in sowing dates have a highly substantial effect on cotton and sesame agronomic traits. This could be ascribed to the effect of climate change on temperature, rainfall, and relative humidity in figure 1.

Cotton that were planted early in April 1st have the length of the developmental stages pre- and post- flowering, which allow to receive the highest heat unit (Figure 1), as well as their ability to effectively absorb water and soil nutrients, increase photo-assimilates in leaves, which reflected on seedling vigor and agronomic traits. Therefore, the highest plant height, more branching, and heaviest seed index weight played an important role in increasing the cotton seed yield per plant by sowing on April 1 compared to the last sowing date under decreasing vegetative period and heat stress (high temperature) during the flowering stage, which resulted in flower abortion and thus the lowest cotton seed yield per plant. Moreover, cotton plants were stressed by certain pests during the late growth stage, especially in cotton sole cultures where relatively high infestation of bollworms was observed (Ghosh, 2004; Dhima *et al*., 2007; Yilmaz *et al*., 2007; Sultan *et al*., 2012; Awad, 2016 and Metwally *et al*., 2016; Tariq *et al*., 2021; Ali *et al*., 2021 and Sankaranarayanan *et al*., 2021).

Late intercropping of sesame with cotton gave a chance to increase seedling vigour of cotton which reflected vegetative growth, it lead to the competitiveness and shade of cotton, also, it played an important role in decreasing effect the intercropping on photosynethetic processes which reflected on the agronomic characteristics of cotton, these data were agreement with obtained by (Oyeogbe *et al*., 2015; Lamlom *et al*., 2020 and El-Shamy, *et al*., 2021). In contrast, early intercropping of sesame into a cotton crop significantly reduced cotton productivity at all cotton sowing dates, followed by moderately reduced productivity when cotton and sesame were sown simultaneously, and slightly reduced productivity when sesame was introduced two weeks after cotton sowing; this may be due to improve vegetative growth of sesame which lead to gave a chance the competitiveness and shade of sesame, this the shading and competitiveness caused decreasing in photosynethetic processes, absorb water and soil nutrients, decrease photo-assimilates in leaves of cotton which reflected on seedling vigour and agronomic traits. Therefore, the shortest plant height, less branching, and less seed index weight played an important role in decreasing the cotton seed yield per plant which reflected on the agronomic characteristics of cotton. This was the same explanation provided in the research of Mourad and El-Mehy, (2021), who found that sunflower sown at an early date simultaneously with sugar beet produced the highest seed yield and its components, while sugar beet showed the opposite trend.

Sesame agronomic traits significantly responded to climate change when the sowing date was changed (Figure 1). Temperatures, precipitation, and relative humidity have all changed due to global climatic factors which affected sesame agronomic where sesame seeds were sown on May 1 in a hot climate, sesame yield per plant increased significantly compared to the two earlier sowing dates in a cool climate because planting in May was the suitable date of sesame which help improving the germination and vegetative growth and improve the ability to effectively absorb water and soil nutrients, increase photo-assimilates in leaves which reflected on seedling vigour and agronomic traits. Also, this could be due to the highest heat units being recessive, which resulted in increased production of photo-assimilates by the photosynthetic process. This increased production of photosynthetic products led to an increase in the yield-related traits studied, which was reflected in a higher sesame yield per hectare for the crops last sown on May 1, which is consistent with the reason given by Ali (2021) and El-Shamy, *et al*. (2021) and Lamlom and Ahmed (2021). On other hand sowing dates in a cool climate cause sesame face unsuitable condition, these led to weakness in seedling vigour which reflected sesame agronomic traits resulting in lower sesame yield per plant and sesame yield per hectare.

In intercropping with early introduction of sesame, the highest increase in sesame yields was attributed to avoidance of shading and competitiveness of cotton as result of increasing seedling vigour of sesame which increase absorb to water and soil nutrient, increase photosynthesis in leaves which reflect on agronomic traits. When sesame sowing was delayed by 2 WAC, sesame production decreased dramatically in intercropping systems (Lamlom *et al*., 2020 and El-Shamy, *et al*., 2021). Moreover, these results are consistent with those of Lamlom and Ahmed (2021) who found that the highest sesame yield (2.83 and 3.60 ardab per hectare^{-1}) was obtained in the first and second seasons, respectively, when sesame plants were grown 15 days before tomato and at 50% of the total density.

Early intercropping of sesame improved its competitive ability and shade tolerance under the conditions of this study. While delayed sowing of sesame into cotton resulted in a significant decrease in sesame productivity at all cotton seed dates, simultaneous sowing of cotton and sesame had a moderate effect, and sesame sown two weeks prior to cotton sowing had a small effect. sesame production changed as result of difference in competitiveness ability of crops as result of changing intercropping date as previously reported by Oyeogbe, *et al*. (2015), Lamlom and Ahmed (2021), El-Shamy, *et al* (2021) and El-Mehy, and Awad (2022). A recent study by Mourad and El-Mehy, (2021) found that sunflower sown at an early date simultaneously with sugar beet gave the highest seed yield and its components, while the trend was reversed for sugar beet.

In general, intercropping enhances the abundance of predators, which in turn prevents the buildup of pests, thus lessening the need of using harmful chemical insecticides. The results on pests agreed with those of Hafez *et al.* (1996); Al-shannaf (1994, 2002, and 2010); Ibrahim (2001 and 2006); Ibrahim *et al.* (2006) and Ibrahim and Al-shannaf (2017), who found that cotton bollworm and sesame capsule borer (*Antigastra catalaunalis*) are the most destructive insects on cotton and sesame crops in sole and intercropping systems. The pests are deterred or repelled from the host-crop by stimuli substance, which can be delivered by intercropping with non-host plants with deterrent or repellent attributes that are appropriate for the target pest (Cook *et al.* 2007). The decline in cotton bollworm infestation could be due to the repellent effect of sesame odors (sesamol and sesamolin) against cotton bollworm and high plant density interrupting the movement of moths, as already mentioned by Vaiyapuri *et al.* (2007), who found that the intensification system of cotton and sesame had moderate and low effects on pest control.

Land equivalent ratio (LER) has been used to compare yields from growing two crops together with yields from growing the same crops in sole culture (Mead and Willey, 1980). Planting cotton before sesame by 2 weeks at all sowing dates caused increasing relative yield of cotton which increasing total relative yield of both crops. This may be due to reduce intra- and inter-specific competition between the two spice crops for basic growth resources and consequently create suitable above- and below-ground conditions for the growth and development of both crops as compared to other treatments, as shown in previous studies by Bhatt *et al.* (2010), Donyavian *et al.* (2018), and Lamlom and Ahmed (2021). The land equivalent ratio of intercropping sesame after 2 weeks with cotton planting on April 1 (2WAC) outperformed the other intercropping patterns as result of increasing the total relative yield of both crops. these results could be due to the planting date of cotton which could reflect on high seed germination, the timely appearance of seedling and the optimum development of the of seedling and the optimum development of the root system which reflect on seed cotton yield in comparison with the other dates.

In agreement with Donyavian *et al.* (2018), Aggressiveness differed between crops, these results may be due to the degree of competition between cotton and sesame for nutrients, carbon dioxide, solar radiation, and water. Intercropping sesame 2 weeks after cotton seeding resulted in the highest aggressiveness; it was positive for cotton and negative for sesame because late intercropping of sesame with cotton gave a chance to increase seedling vigour of cotton which reflected vegetative growth and increasing the competitiveness and shade of cotton as compared sesame. On other hand, intercropping sesame before cotton gave a chance of sesame to increase seedling vigour which reflected vegetative growth and increasing the competitiveness and shade of sesame. Results are consistent with those of El-Mehy and Awad, (2021) who stated that aggressivity values of both crops differ by sesame intercropping date varied.

The relative crowding coefficient of displacement (K) is the measure of the relative dominance of one species over the other in intercropping (De wit, 1960). If the product of the two coefficients (K cotton × K sesame) is greater than one, there is a yield advantage, if the value of K is one, there is no yield advantage, and if it is less than one, there is no yield advantage and the system is at a disadvantage (Khan *et al.*, 2001). The relative displacement coefficient (K) results showed higher values than one for the intercropping patterns on April 1 (2 WACS), while April 15 (2 WBCS) had the lowest value. The results were consistent with those of Donyavian *et al.* (2018). For all sowing dates, planting cotton before sesame reduced intra- and inter-specific competition between the two spice crops for vital growth resources, which according to Donyavian *et al.* (2018) creates favorable above- and below-ground conditions for the growth and development of both crops.

The major benefit of intercropping was to increase the profits of the growers (Bhatt *et al.*, 2010,; Masri and Safina, 2015; Zohry *et al.*, 2017 and Donyavian *et al.*, 2018). It is considered the best economic return obtained when intercropping sesame after 15 days of sowing cotton on the April 1st, because the total return of cotton was not clearly affected by the sesame intercropping, with the addition of an additional economic return from the sesame intercropping, and this is because the productivity of cotton was not clearly affected, which was reflected in economic return. On other hand the lowest values of gross yield were obtained by the intercropping of sesame before cotton on the third date of cotton because the additional yield as a result of increasing the productivity of intercropping sesame compared to other intercropping treatments did not compensate for the large loss caused by sesame in cotton productivity as a result of intercropping at this time.

CONCLUSION

In Egypt, where cotton is the main fiber crop, it might be possible to grow sesame along with cotton without any negative impact on cotton. A place must be found where sesame can be grown on existing cotton areas without competing with summer crops and without incurring additional costs from competition between summer crops (cotton, corn, and rice). The best way to increase productivity, LER and total return as well as reduce pest pressure is to intercrop sesame after two weeks with cotton planted on April 1, which produce the highest LER (1.21) and cotton seed yield 23.93 kentar addition to 334.19l kg per hectare. All intercropping treatments produced the best total return as compared to sole culture in the three cotton dates. The results showed that intercropping sesame after two weeks with cotton in April 1 outperformed the other intercropping patterns, it gave 66498.39 L.E in the combined analysis. Moreover, this system saved 21% of the area compared to cotton alone and reduced the competition between the two crops. Therefore, the intercropping of sesame is recommended two weeks after the cultivation of cotton in April 1 by sowing a row of sesame in the middle of the cotton bed (140 cm wide) with a distance of 10 cm between plants/hills to increase oilseed production, land efficiency and total return in Egypt and reduce pest pressure.

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