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RATIONALIZATION OF MINERAL NITROGEN FERTILIZATION AND ITS IMPACTS ON PROFITABILITY OF INTERCROPPING SESAME WITH COTTON

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ABSTRACT: A two-year field experiment was conducted at Sakha Agricultural Research Station in Kafr El-Sheikh Governorate, Egypt, during the summer seasons of 2023 and 2024. The treatments involved three nitrogen (N) fertilizer rates (60, 75, and 90 kg N/fed) for cotton and four different sesame plant densities (12.5%, 25.0%, 37.5%, and 50.0% of sole planting). This study aimed to identify the optimal N fertilizer rate and sesame plant density for intercropping with cotton to increase the yield of both crops, land-use efficiency, and economic return in the North Delta region. A split-plot design was employed to conduct the experiment, with four replicates for each treatment. Sesame plant densities were dispersed throughout the subplots, while N fertilizer rates were assigned to the main plot. The results showed that an intercropping system consisting of 100% cotton and 50% sesame on a 140 cm wide bed with 75 kg N/fed produced the highest yield of both crops. One row of sesame, with two plants per hill spaced 15 cm apart, was planted in the center of the beds, while cotton was planted on both sides. This led to enhanced seed yield and quality for both crops, along with improved Land Equivalent Ratio (LER) and economic returns.

Key words: Intercropping, seed quality, LER, economic return.

INTRODUCTION

For many years, Egyptian cotton (*Gossypium barbadense* L.) was highly valued, with the majority of the crop being exported to European countries. It is a crucial economic crop in Egypt and globally, used in various industrial products, and contributes significantly to national income (El-Shamy *et al*., 2023). Animal feed contains cottonseed meal because of its high protein and energy content. Cotton is a major fiber crop worldwide, ranking second to soybean as a plant protein source, with its oil being the fifth most widely used edible oil globally (Ghoprial *et al*., 2021). Sesame (*Sesamum indicum* L.) is highly prized for its excellent oil quality and rich micronutrient content, ranking second to olive oil in nutritional value. Sesame seeds, with high oil content (50–60%) and protein (20%), along with carbohydrates (14–20%), fiber, vitamin E, and minerals, are a valuable commodity. The majority of sesame production is used for oil and sesame seed meals, with the rest utilized in the food industry, confections, and beverages (Berhe *et al*., 2023).

Unfortunately, there is a decline in sesame land, which reached 88623 feddan in 2023, as a result of higher competition with other strategic summer crops, such as cotton (255121 feddan). Accordingly, there is a need to expand the scope of sesame cultivation through the use of an intercropping system. Specifically, intercropping is the most effective tool for maintaining the area of oil crops without a significant change in crop structure (Bulletin of Agricultural Statistics, 2023). In a study by Lamlom *et al*. (2020), it was demonstrated that intercropping sesame with cotton (25% sesame + 100% cotton) following the harvest of Egyptian clover led to increased yields of cotton seeds, protein, and oil per hectare. Researchers also found that intercropping sesame with cotton significantly increased the levels of oleic and linoleic acids (unsaturated fatty acids) in

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the oil of seed cotton compared to growing cotton alone. Moreover, intercropping cotton and sesame at a 1:1 row ratio significantly increased seed cotton yield (Sathishkumar *et al*., 2023).

Nitrogen (N) is an essential plant nutrient that influences the production of protein, protoplasm, and chlorophyll, leading to increased cell volume, leaf area, and photosynthetic activity. Many developing countries face nutrient deficiencies among their populations (Dhaliwal *et al.,* 2022). Although cotton and sesame are often grown together, further research is needed to determine optimal planting density and N fertilization. The quantity and quality of cotton yield traits increased when cotton plants were planted 25 or 30 cm apart, with double plants per hill, and the soil was fertilized with 75 kg N/fed (Ghoprial, 2018). Meanwhile, Panhwar *et al.* (2018) found that higher N fertilizer levels led to a significant increase in plant height, boll weight, seed index, seed cotton yield/plant, seed cotton yield/unit area, and lint cotton yield/unit area. However, Emara and Abdel-Aal (2017) found that a high level of fertilizer N did not have a significant effect on seed index. In another study, Abdel-Aal *et al.* (2019) found that applying a high level of N fertilizer (60 or 75 kg N/fed) in three or four equal doses resulted in increased productivity of the Giza 94 cotton variety.

With respect to the plant density of sesame, Kadam *et al*. (2015) showed that a plant density of 166666 plants/ ha significantly increased the protein content in seeds of sesame or cotton compared to other plant densities, while the oil content in seeds remained unaffected. Moreover, El-Shamy *et al*. (2021) reported that the number of capsules/plant and plant height were significantly impacted by sesame density. They added that the density of sesame plants had a significant effect on all traits of cotton except plant height. Thus, it is important to apply N fertilizer in a sufficient quantity required for intercrops in order to increase yields of sesame and cotton under an appropriate plant density of sesame. Farmers benefit more from the intercropping system, which also serves as insurance against crop failure by stabilizing production and increasing overall returns (Singh *et al*., 2000). The most effective intercropping pattern for achieving the highest land equivalent ratio (LER) and monetary profit was 3 cottons: 1 sesame (Donyavian *et al*., 2018). Therefore, this study aims to identify the optimal N fertilizer rate and sesame plant density intercropped with cotton to increase the yield of terrace crops, improve seed quality, enhance land-use efficiency, and increase economic return in the North Delta region.

MATERIALS AND METHODS

A two-year field experiment was conducted at the Sakha Agricultural Research Station in Kafr El-Sheikh Governorate, Egypt, during the summer seasons of 2023 and 2024. The net area of the experimental plot was maintained at 12.6 m², with three beds (140 cm wide) per plot (4.2 m wide x 3.0 m long). Furrow irrigation was the main irrigation system in the region. The design of the experiment was laid out in a split-plot with four replicates. N fertilizer rates (60, 75, and 90 kg N/fed) were placed in the main plots, and the sesame plant densities were placed in the subplots. Sesame was planted (in one row with two plants per hill) in the center of the terrace at a rate of 50% and with a 15 cm spacing. Besides, 37.5% of the sole crop resulted from planting one row of sesame in the middle of the bed at 20 cm between hills. Additionally, 25.0% of the sole crop resulted from planting one row of sesame in the middle of the bed at 30 cm between hills. Additionally, 12.5% of the sole crop resulted from planting one row of sesame in the middle of the bed at 60 cm between hills. The planting density for cotton was 48,000 plants/fed (seeding rate 30 kg/fed), and for sesame, 80,000 plants/fed (seeding rate 4 kg/fed Giza 97 cotton seeds were sown on April 14 and 16 for the 2023 and 2024 seasons, respectively, with two plants per hole at 25 cm apart. Sesame seeds of Shandawel cultivar 3 were sown on May 1 and 3 for the 2023 and 2024 seasons, respectively. Sole sesame planting was planted 15 cm apart, leaving two plants per hole. The sesame harvest was scheduled for August 1 and 3, while cotton was harvested on November 5 and 9 in the first and second seasons, respectively. Both cotton and sesame seeds were sown regularly and according to technical recommendations. During soil preparation, 150 kg/fed of calcium superphosphate fertilizer (15.5% P_2O_5) was added.

Soil particle size distribution and chemical analyses were conducted using the method outlined by Page *et al.* (1982) after randomly selecting soil samples from 0 to 30 cm below the soil surface during the two growth seasons. The results are shown in Table 1.

Table 1. Physical and chemical properties of the experimental site during the 2023 and 2024 seasons.

Properties		2023 season	2024 season
A: Particle size distribution:			
Sand, %		9.72	9.73
Silt, %		30.24	29.99
Clay, %		60.04	60.28
Texture		Clay	Clay
B: Chemical analysis:			
pH		7.75	7.82
EC (dS/m)		1.45	1.92
Organic matter (g kg^{-1})		11.40	10.50
Total N (%)		0.14	0.13
Total carbonate (%)		2.20	2.21
CEC (meq/100 g soil)		41.38	41.60
SP (%)		78.40	78.52
SAR		4.58	4.67
Available nutrients (mg/kg)	N	26.20	27.10
	P	8.70	8.55
	K	250.60	260.40
	Zn	6.15	6.00
	Mn	14.10	13.75
Soluble cations (meq/L)	Ca^{++}	4.11	4.62
	Mg^{++}	1.80	1.92
	Na^{+}	8.00	12.20
	K^{+}	0.59	0.46
Soluble anions (meq/L)	CO_3^{--}	0.00	0.00
	HCO_3^{-}	2.01	2.59
	CL^{-}	6.27	8.51
	SO_4^{--}	6.22	8.10

Data recorded

1- Cotton crop

a- Seed cotton yield and its components

The following traits were measured on ten guarded cotton plants from each subplot at harvest: plant height (cm), boll number per plant, boll weight (g), 100-seed weight (g), lint boll weight (g), and seed cotton yield per plant (g).

By harvesting the plants in sub-plot, the yield per fed (kentar) of seed cotton (one fed = 4200 m^2 and one kentar = 157.5 kg) was calculated based on the sub-plot area. After ginning the seeds were separated and the seed yield/fed was weighted (kg). By multiplying the seed protein content by the seed yield per fed (kg), the protein yield per fed (kg) was calculated. Seed oil content was multiplied by seed yield per fed (kg) to determine oil yield per fed (kg).

b- Seed cotton quality

Chemical compositions of seed protein and oil contents (%) were analyzed in the Physiology Research Department at the Sakha Agricultural Research Station, Field Crops Research Institute, Agricultural Research Center. Seed protein content (%) was calculated by multiplying total N in the seed by a factor of 6.25 (He *et al.,* 2013). The seed oil content (%) was calculated using a Soxhlet apparatus according to AOAC (2000).

2. Sesame crop

a- Seed yield and its components

The following traits were measured on ten guarded sesame plants from each subplot at harvest: plant height (in cm), number of capsules per plant, 1000-seed weight (in grams), and seed yield per plant (in grams). Seed yield per fed (ardab) (one ardab = 120 Kg) was recorded on the basis of sub-plot area by harvesting all plants of each sub-plot and converted to seed yield per fad. Protein yield per fed (kg) was calculated by multiplying seed protein content (%) by seed yield per fed (kg). Oil yield per fed (kg) was calculated by multiplying seed oil % by seed yield/fed (kg).

b- Seed quality

The chemical composition of the seed protein and oil content (%), saturated and unsaturated fatty acids, was analyzed at the Physiology Research Department, Sakha Agricultural Research Station, Field Crops Research Institute, Agricultural Research Center. The chemical composition of the crude protein and oil content was analyzed. The crude protein content was calculated by multiplying the total nitrogen in the seeds by a factor of 6.25 (He *et al.,* 2013). Seed oil content was determined as described in the AOAC (2000) method, using a Soxhlet apparatus. Identifying fatty acids composition was determined using Gas Chromatography.

3. Competitive relationships

The following competitive relationships and yield advantages were the Land Equivalent Ratio (LER).

a- Land Equivalent Ratio (LER)

LER is important for measuring the efficiency of intercropping advantages in utilizing environmental resources compared to sole cropping. It is calculated by adding the partial LER for cotton and sesame crops. LER can also be described in terms of the relative yield of individual crops in the cropping system, and the relative yield was quantified as stated in the equation of Willey and Rao (1980).

$$\mathrm{LER} = \frac{\mathrm{Yab}}{\mathrm{Yaa}} + \frac{\mathrm{Yba}}{\mathrm{Ybb}}$$

Where: Yaa and Ybb were the sole crops, a (cotton) and b (sesame), respectively. Yab is the mixture yield of a, and Yba is the mixture yield of the b crop. If the value of LER is > 1, LER is < 1, or LER is = 1, then intercropping is considered to be advantageous, disadvantageous, and neither advantageous nor disadvantageous, respectively

b. Economic evaluations

The gross return from each treatment was calculated in Egyptian Pounds (LE), as stated by the Egyptian Ministry of Agriculture and Land Reclamation, Economic Affairs Sector, Agricultural Statistics. The market price of seed cotton yield was 12,500 LE/kantar, and sesame was 47.5 LE/kg, as the average for both seasons.

Net return = Total income – Total costs.

Statistical analysis

Combined analysis was done for the data of the two seasons after homogeneity test. To find significant differences between treatments, Steel and Torrie's (1984) analysis of variance was applied to all collected data. LSD was used to compare treatment mean differences at a 5% probability level.

RESULTS AND DISCUSSION

1. Seed cotton yield and its components

The data in Table 2 indicate significant effects of nitrogen fertilization rates on all studied cotton traits. The moderate nitrogen fertilization rate (75 kg N/fed), except for plant height, significantly improved all studied cotton traits, followed closely by the rate of 90 kg N/fed. In contrast, the lowest values for cotton traits were recorded when

60 kg N/fed was added. These results indicated that low nitrogen fertilization rates slow growth and development, which in turn leads to lower yields. Applying 75 kg of nitrogen/fed resulted in increases in plant height, number of bolls per plant, boll weight, 100-seed weight, lint boll weight, cotton seed yield per plant, and cotton seed yield per fed were 9.46, 11.14, 16.84, 14.33, 8.70, 3.09, 19.32, and 19.49%, respectively, compared to 60 kg nitrogen/fed.

Meanwhile, the application of 90 kg N/fed increased plant height, number of bolls/plant, boll weight, seed yield/plant, lint boll weight, cotton seed yield/plant, cotton seed yield/fed and seed yield/fed by 14.43, 6.08, 6.32, 9.58, 6.09, 1.04, 6.21, and 6.35%, respectively, compared with 60 kg N/fed. These results underscore the importance of selecting the optimal N fertilizer rate for achieving maximum cotton growth and yield in intercropping systems.

The low soil concentration of accessible N (as shown in Table 1) likely influenced these outcomes. Adequate N levels can enhance plant nutrient absorption, photosynthesis, and yield components, ultimately improving crop health and productivity. Soil testing and monitoring plant nutrient levels are crucial for determining the most effective N application rate in intercropped cotton systems.

Table 2. Effect of nitrogen fertilization rates, sesame plant density, and their interaction on seed cotton yield and its component content in the combined data across the two seasons

Treatments		Plant height (cm)	Bolls number/plant	Boll weight (g)
N fertilizer rates				
60 kg N/fed		153.14	18.59	2.85
75 kg N/fed		167.62	20.66	3.33
90 kg N/fed		175.24	19.72	3.03
LSD at 5% significance level		0.83	0.33	0.13
Sesame plant densities				
100% cotton + 12.5% sesame		162.13	19.09	2.94
100% cotton + 25.0% sesame		164.39	19.61	3.08
100% cotton + -37.5% sesame		166.38	19.86	3.09
100% cotton + 50.0% sesame		168.43	20.06	3.13
LSD at 5% significance level		0.66	0.25	0.13
Interaction				
60 kg N/fed	100% cotton + 12.5% sesame	150.38	17.79	2.76
	100% cotton + 25.0% sesame	152.83	18.45	2.85
	100% cotton + 37.5% sesame	153.81	18.89	2.87
	100% cotton + 50.0% sesame	155.55	19.18	2.94
75 kg N/fed	100% cotton + 12.5% sesame	163.54	20.25	3.09
	100% cotton + 25.0% sesame	166.77	20.67	3.52
	100% cotton + 37.5% sesame	168.68	20.78	3.34
	100% cotton + 50.0% sesame	171.47	20.92	3.36
90 kg N/fed	100% cotton + 12.5% sesame	172.46	19.22	2.98
	100% cotton + 25.0% sesame	173.57	19.71	3.02
	100% cotton + 37.5% sesame	176.66	19.88	3.05
	100% cotton + 50.0% sesame	178.26	20.07	3.06
LSD at 5% significance level		1.07	NS	0.02
Sole cotton		179.65	20.98	3.54

Table 2. Continued.

Treatments		100-seed weight (g)	Lint boll weight (g)	Seed cotton yield/ plant	Seed cotton yield/fed (kentar)	Seed yield/fed (kg)
N fertilizer rates						
60 kg N/fed		10.75	1.15	47.26	8.85	813.59
75 kg N/fed		12.29	1.25	48.72	10.56	972.22
90 kg N/fed		11.78	1.22	47.92	9.40	865.27
LSD at 5% significance level		0.02	0.02	0.04	0.07	1.49
Sesame plant densities						
100% cotton + 12.5% sesame		11.22	1.16	47.67	9.21	846.55
100% cotton + 25.0% sesame		11.55	1.20	47.89	9.47	871.47
100% cotton + -37.5% sesame		11.69	1.21	48.03	9.74	896.92
100% cotton + 50.0% sesame		11.95	1.23	48.27	9.99	919.92
LSD at 5% significance level		0.02	0.02	0.04	0.07	1.45
Interaction						
60 kg N/fed	100% cotton + 12.5% sesame	10.33	1.08	47.01	8.18	749.79
	100% cotton + 25.0% sesame	10.74	1.15	47.30	8.68	798.79
	100% cotton + 37.5% sesame	10.76	1.18	47.32	8.99	827.31
	100% cotton + 50.0% sesame	11.16	1.19	47.41	9.55	878.84
75 kg N/fed	100% cotton + 12.5% sesame	11.96	1.22	48.38	10.38	955.19
	100% cotton + 25.0% sesame	12.19	1.24	48.59	10.48	964.94
	100% cotton + 37.5% sesame	12.45	1.25	48.78	10.67	981.88
	100% cotton + 50.0% sesame	12.53	1.26	49.14	10.73	987.39
90 kg N/fed	100% cotton + 12.5% sesame	11.35	1.20	47.64	9.07	834.67
	100% cotton + 25.0% sesame	11.73	1.21	47.78	9.25	851.23
	100% cotton + 37.5% sesame	11.87	1.22	47.99	9.58	881.59
	100% cotton + 50.0% sesame	12.15	1.23	48.25	9.71	893.55
LSD at 5% significance level		0.04	0.03	0.80	0.80	1.74
Sole cotton		12.55	1.27	49.52	10.98	1010.16

These results, confirmed by another study, indicate that the optimal N-fertilizer dosage is 75 kg N per feddan, followed by 60 kg N per fed, administered in three equal doses, to achieve excellent productivity (Abdel-Aal *et al.*, 2019). According to Ibrahim *et al*. (2022), applying 100% N (142.8 kg N/ha) fertilizer resulted in the highest lint cotton production, while applying 125% N fertilizer to the Giza 97 cotton cultivar resulted in the highest seed cotton yield under the conditions of the Sakha region in Kafr El-Sheikh Governorate. These findings align with previous research by Ghoprial *et al*. (2021), Dhaliwal *et al*. (2022), Kotadiya *et al.* (2023), and Hussain *et al.* (2025).

The densities of sesame plants had a significant effect on seed cotton yield and yield components (Table 2). The results indicated that increasing the density of sesame plants from 12.5% to 50% resulted in a notable improvement in plant height, boll number per plant, boll weight, seed cotton yield per plant, fiber boll weight, seed cotton yield per plant, and seed cotton yield per fad. These data show that intercropping sesame with cotton at higher densities, 37.5% or 50%, can enhance cotton growth and yield.

The positive effects of higher sesame plant density on cotton properties highlight the potential benefits of utilizing intercropping techniques in agricultural practices. Higher sesame plant density could potentially increase productivity by controlling weeds or pests in cotton fields. As previously noted by Awad *et al.* (2023), the intensification pattern of sesame with cotton may have obvious impacts on pest control. These results suggest that farmers can benefit from incorporating intercropping practices to enhance their agricultural yields. Furthermore, these findings could be attributed to intraspecific competition having a greater negative impact than interspecific competition for nutrients, water, and light. According to Adler *et al.* (2018), sometimes intraspecific competition typically has negative effects, but interspecific competition can result in positive outcomes. These results are similar to those obtained by El-Shamy *et al.* (2021), Koriem (2023), and Sathishkumar *et al.* (2023).

Interaction between N fertilization rates and density of sesame plants

The data in Table 2 show that the interaction between N fertilizer rates and sesame plant densities significantly affected the yield and yield components of cotton, except for the number of bolls per plant. The highest values of plant height, boll weight, 100-seed weight, lint boll weight, seed cotton yield per plant, and seed cotton yield per fad were produced by a 75 kg N/fed fertilizer rate along with a plant density of 50.0%, followed closely by a 33.3% sesame plant density.

a. Seed cotton quality

The data in Table 3 indicate significant differences in nitrogen fertilization rates concerning protein percentage and protein yield per fad, oil percentage and oil yield per fad. The highest values for cotton characteristics were achieved at a fertilizer rate of 75 kg nitrogen/fed, which increased the above-mentioned characteristics, compared to 60 kg N/fed by 10.61, 31.69, 7.28, and 27.83%, respectively. These results indicate that increasing nitrogen fertilization rates above 75 kg N/fed may not significantly improve cotton seed quality. So, farmers should carefully consider the most effective nitrogen fertilization rate to improve cotton seed quality.

Significant effects of sesame plant density on protein and oil yields per fed were observed, as shown in Table 3. However, seed protein and oil content (%) were not significantly affected by plant densities of sesame. Further, interaction effects between nitrogen fertilization rates and sesame plant density on cotton seed quality were not significant (Table 3). These results indicate that sesame plant density or the interaction between nitrogen fertilization rates and sesame plant density has no significant impact on the quality of cotton seeds.

2. Sesame seed yield and its components

Plant height, number of capsules/plant, 1000 seed weight, seed yield per plant, and seed yield per fad were affected by nitrogen fertilization rates (Table 4). The highest nitrogen fertilization rate (90 kg N/fed) significantly improved plant height compared to other fertilization rates. In contrast, the nitrogen fertilization rate (75 kg N/fed) recorded the highest values of seed yield and its components. Increasing the nitrogen fertilization rate up to 90 kg N/fed may lead to excessive vegetative growth in sesame. This negatively affects fruit development. Golan *et al.* (2022) obtained similar results, finding that the nitrogen excess and deficiency in terraces can significantly increase plant productivity. Applying 75 kg N/fed increased plant height, number of capsules/plant, 1000 seed weight, and seed yield/fed by 15.12, 20.35, 10.57, and 10.46%, respectively, compared to 60 kg N/fed.

Sesame plant density had a significant effect on seed yield and its components (Table 4). The results indicated that increasing sesame plant density from 12.5% to 50% resulted in significant improvements in plant height, number of capsules/plant, 1000-seed weight, and seed yield/fed. These improvements amounted to 11.94, 5.69, 8.27, and 268.46%. The results indicate that increasing sesame plant density can enhance productivity and improve its components. These results confirm the benefits of improving plant density in increasing agricultural production in mixed cropping systems.

The data in Table 4 indicate significant differences between the interaction of nitrogen fertilization rates and sesame plant density in the number of capsules, 1000 seed weight, and crop productivity per fed. However, there were no significant differences of the interaction on plant height and seed yield per plant. These results suggest that the interaction between nitrogen fertilization rates and sesame plant density has a more pronounced effect on some productivity-related traits than others. Further analysis may be necessary to understand the specific factors influencing these results.

Table 3. Effect of seed cotton quality as affected by N fertilizer rates, sesame plant densities, and their interaction on content in the combined data across the two seasons.

Treatments		Seed protein content (%)	Protein yield (kg/fed)	Seed oil content (%)	Oil yield (kg/fed)
N fertilizer rates					
60 kg N/fed		24.02	195.42	18.28	148.72
75 kg N/fed		26.58	258.42	19.61	190.65
90 kg N/fed		26.05	225.40	18.87	163.28
LSD at 5% significance level		1.64	26.04	0.99	16.16
Sesame plant densities					
100% cotton + 12.5% sesame		24.48	207.24	18.26	154.58
100% cotton + 25.0% sesame		25.63	223.36	19.06	166.10
100% cotton + -37.5% sesame		25.94	232.66	19.11	171.40
100% cotton + 50.0% sesame		26.12	240.28	19.25	177.08
LSD at 5% significance level		NS	22.63	NS	15.51
Interaction					
60 kg N/fed	100% cotton + 12.5%sesame	21.59	161.88	16.63	124.69
	100%cotton +25.0% sesame	24.39	194.82	18.78	150.01
	100% cotton + 37.5% sesame	24.86	205.67	18.82	155.70
	100% cotton + 50.0% sesame	25.27	222.08	18.88	165.92
75 kg N/fed	100% cotton + 12.5% sesame	26.12	249.50	19.46	185.88
	100% cotton + 25.0% sesame	26.47	255.42	19.58	188.94
	100% cotton + 37.5% sesame	26.82	263.34	19.63	192.74
	100% cotton + 50.0% sesame	26.91	265.71	19.78	195.31
90 kg N/fed	100% cotton + 12.5% sesame	25.73	214.76	18.68	155.92
	100% cotton + 25.0% sesame	26.01	221.40	18.81	160.12
	100% cotton + 37.5% sesame	26.12	230.27	18.89	166.53
	100% cotton + 50.0% sesame	26.32	235.18	19.08	170.49
LSD at 5% significance level		NS	NS	NS	NS
Sole cotton		26.92	271.94	19.79	199.91

Table 4. Effect of nitrogen fertilization rates, sesame plant density, and their interaction on sesame seed yield and its components in the combined data across the two seasons.

Treatments		Plant height (cm)	Number of capsules/plant	1000-seed weight (g)	Seed yield/ plant (g)	Seed yield/fed (kg)
N fertilizer rates						
60 kg N/fed		136.84	45.78	3.76	8.61	232.36
75 kg N/fed		153.75	55.10	4.61	9.52	256.66
90 kg N/fed		157.53	48.26	3.93	8.27	218.38
LSD at 5% significance level		3.87	2.26	1.94	NS	0.35
Sesame plant densities						
100% cotton + 12.5% sesame		141.13	48.29	3.99	8.55	99.77
100% cotton + 25.0% sesame		145.91	49.32	4.07	8.73	181.56
100% cotton + -37.5% sesame		152.46	50.18	4.00	8.89	292.74
100% cotton + 50.0% sesame		157.99	51.04	4.32	9.04	367.62
LSD at 5% significance level		2.71	2.61	5.86	NS	0.40
Interaction						
60 kg N/fed	100% cotton + 12.5% sesame	128.08	44.10	3.65	8.36	102.03
	100% cotton + 25.0% sesame	134.30	45.73	3.85	8.56	179.67
	100% cotton + 37.5% sesame	138.53	46.21	3.60	8.67	287.87
	100% cotton + 50.0% sesame	146.48	47.07	3.92	8.84	359.87
75 kg N/fed	100% cotton + 12.5% sesame	145.87	53.85	4.47	9.21	108.03
	100% cotton + 25.0% sesame	149.18	54.52	4.49	9.44	191.70
	100% cotton + 37.5% sesame	157.22	55.73	4.60	9.56	323.61
	100% cotton + 50.0% sesame	162.74	56.32	4.91	9.86	403.30
90 kg N/fed	100% cotton + 12.5% sesame	149.44	46.94	3.90	8.08	97.41
	100% cotton + 25.0% sesame	154.26	47.72	3.87	8.2	173.30
	100% cotton + 37.5% sesame	161.63	48.67	3.82	8.34	266.74
	100% cotton + 50.0% sesame	164.76	49.73	4.14	8.44	339.70
LSD at 5% significance level		NS	3.72	9.96	NS	0.57
Sole sesame		166.47	56.51	4.99	8.36	800.00

a-Sesame seed quality

The data in Table 5 indicate significant differences in nitrogen fertilization rates, protein percentage and protein yield per fed, and oil percentage and oil yield per fad of sesame. These results highlight the effect of nitrogen fertilization rates on the qualitative sesame crops, with percentages reaching 5.06, 16.03, 5.03, and 16.02%. The highest values for sesame characteristics were achieved at a fertilization rate of 75 kg nitrogen/fed compared with 60 kg N/fed. These results indicate that increasing nitrogen fertilization rates above 75 kg N/fed can significantly improve sesame seed quality. Farmers should carefully consider the most effective nitrogen fertilization rate for improving sesame seed quality.

There are significant effects of sesame plant density on seed quality of sesame Table (5). Increasing sesame plant density from 25% up to 50% increased seed protein content, protein yield/fed, oil seed %, and oil yield /fed by 2.87%, 279.09%, 0.88%, and 271.75%, respectively. This result may be attributed to the increasing plant densities of sesame, which increase intraspecific competition and reduce the photosynthetic capacity and carbohydrate storage in the seeds, potentially leading to a higher concentration of protein and oil in the seeds. Caliskan *et al.* (2004) showed that increasing sesame plant density significantly increases the seed oil content % and yields of protein and oil / ha.

The data in Table 5 indicated that the interaction between nitrogen fertilization rates and sesame plant density has a significant effect on sesame seed quality. A combination of a fertilization rate of 75 kg N/fed with 50% plant density of sesame had the highest values of sesame seed quality. Conversely, the lowest values of seed quality were recorded with fertilization rate of 60kg N/fed and 25% sesame plant density.

The data in Table 5 showed significant effects of nitrogen fertilization rates on seed quality traits and fatty acid content. The highest nitrogen fertilization rate (75 kg N/fed) significantly improved the fatty acid content (linoleic, oleic, stearic, and palmitic). Conversely, the lowest values for seed quality traits were observed with the addition of 60 kg N/fed. The addition of 75 kg N/fed significantly increased caprice, linolenic, linoleic, oleic, stearic, and palmitic fatty acids by 13.79, 58.05, 15.91, 3.08, 2.90, 4.87, and 1.77%, respectively, compared to the addition of 60 kg N/fed.

Table 5. Effect of seed cotton quality and fatty acids content as affected by N fertilizer rates, sesame plant densities, and their interaction on content in the combined data across the two seasons

Treatments		Seed protein content (%)	Protein yield/fed (kg)	Seed oil content (%)	Oil yield/fed (kg)
		N fertilizer rates			
60 kg N/fed		23.89	55.51	48.72	113.19
75 kg N/fed		25.10	64.41	51.17	131.32
90 kg N/fed		26.74	58.38	53.63	117.12
LSD at 5% significance level		0.12	0.60	2.84	0.39
		Sesame plant densities			
100% cotton + 12.5% sesame		25.07	25.01	50.98	50.86
100% cotton + 25.0% sesame		25.38	46.08	51.70	93.86
100% cotton + 37.5% sesame		25.63	75.01	51.69	151.32
100% cotton + 50.0% sesame		25.79	94.81	51.43	189.07
LSD at 5% significance level		0.15	0.50	1.53	0.03
		Interaction			
60 kg N/fed	100% cotton + 12.5% sesame	23.63	24.11	46.34	47.28
	100% cotton + 25.0% sesame	24.24	43.54	49.04	88.10
	100% cotton + 37.5% sesame	24.51	70.56	50.40	145.09
	100% cotton + 50.0% sesame	24.90	89.61	50.12	180.35
75 kg N/fed	100% cotton + 12.5% sesame	26.13	28.22	54.44	58.81
	100% cotton + 25.0% sesame	26.13	50.09	54.23	103.95
	100% cotton + 37.5% sesame	26.55	85.90	53.35	172.65
	100% cotton + 50.0% sesame	26.65	107.46	53.14	214.29
	100% cotton + 12.5% sesame	26.48	25.79	52.18	50.82
90 kg N/fed	100% cotton + 25.0% sesame	25.25	43.76	51.85	89.85
	100% cotton + 37.5% sesame	25.46	67.91	51.33	136.92
	100% cotton + 50.0% sesame	25.76	87.51	51.05	173.40
LSD at 5% significance level		0.26	0.85	2.60	0.06
Sole sesame		26.60	212.76	54.39	435.12

Table 5. Continued.

Treatments		Fatty acids contents in sesame seed (%)						
		Caprice (%)	Arachidic (%)	Linolenic (%)	Linoleic (%)	Oleic (%)	Stearic (%)	Palmitic (%)
N fertilizer rates								
60 kg N/fed		0.58	6.84	0.44	45.10	32.75	4.10	10.19
75 kg N/fed		0.66	3.97	0.51	46.49	33.70	4.30	10.37
90 kg N/fed		0.62	6.52	0.49	44.86	32.97	4.25	10.29
LSD at 5% significance level		0.29	0.03	0.01	0.29	1.99	0.02	0.02
Sesame plant densities								
100% cotton + 12.5% sesame		0.60	5.38	0.46	45.02	34.17	4.15	10.22
100% cotton + 25.0% sesame		0.61	4.72	0.48	45.52	34.21	4.20	10.26
100% cotton + 37.5% sesame		0.63	3.77	0.49	45.87	34.69	4.25	10.30
100% cotton + 50.0% sesame		0.63	3.55	0.50	45.93	34.76	4.28	10.35
LSD at 5% significance level		0.24	0.03	0.01	0.35	NS	0.01	0.01
Interaction								
60 kg N/fed	100% cotton + 12.5% sesame	0.55	9.85	0.42	42.89	32.19	4.01	10.09
	100% cotton + 25.0% sesame	0.57	9.28	0.44	42.91	32.56	4.08	10.16
	100% cotton + 37.5% sesame	0.60	9.04	0.45	42.92	32.59	4.16	10.24
	100% cotton + 50.0% sesame	0.59	8.56	0.46	42.97	32.96	4.18	10.28
75 kg N/fed	100% cotton + 12.5% sesame	0.64	1.51	0.48	47.06	35.72	4.25	10.34
	100% cotton + 25.0% sesame	0.66	1.12	0.50	47.35	35.72	4.28	10.37
	100% cotton + 37.5% sesame	0.67	0.53	0.53	47.76	35.82	4.32	10.37
	100% cotton + 50.0% sesame	0.67	0.20	0.54	47.85	35.94	4.36	10.44
90 kg N/fed	100% cotton + 12.5% sesame	0.60	5.80	0.47	45.20	33.49	4.18	10.26
	100% cotton + 25.0% sesame	0.61	4.33	0.48	45.70	34.36	4.25	10.27
	100% cotton + 37.5% sesame	0.63	3.71	0.50	45.73	34.85	4.28	10.30
	100% cotton + 50.0% sesame	0.64	3.45	0.51	45.80	34.97	4.30	10.33
LSD at 5% significance level		0.49	NS	NS	0.54	NS	0.02	0.02
Sole sesame		0.68	0.07	0.54	47.89	35.99	4.38	10.45

Sesame plant density had a significant effect on saturated and unsaturated fatty acids (Table 5). Except for oleic acid, increasing sesame plant density from 12.5% to 50% resulted in an increase in seed content of caprice, arachidic, linolenic, linoleic, oleic, stearic, and palmitic with a ratio of 5.00, 65.98, 8.69, 2.02, 3.13, and 1.27%, respectively. These results suggest that increasing plant density may change the accumulation of saturated and unsaturated fatty acids in sesame seeds.

The interaction between nitrogen fertilization and the sesame plant significantly affected the saturated and unsaturated fatty acid content of caprice, linoleic, stearic, and palmitic acids (Table 5). This indicates that the combination of the second nitrogen fertilization rate (75 kg N) and the highest sesame plant density (50%) can positively affect the contents of caprice, linolenic, and oleic acids in sesame seeds.

3. Competitive relationships

a. LER

The interactions between N fertilizer rates and sesame plant densities in the intercropping system of sesame and cotton, as well as the competitive relationships, are shown in Table 6. Except for the 12.5% sesame plant density, the other intercropping treatments had LER values greater than one, which confirms the high efficiency of the suggested intercropping system. The same table also indicated that increasing the plant density of sesame maximized LER, especially at 75 kg N/fed, followed by 90 kg N/fed. The highest LER value of 1.48 was achieved by intercropping cotton at 100% and sesame at 50.0% with a nitrogen fertilizer rate of 75 kg/fed. Conversely, the intercropping system (100% cotton + 12.5% sesame) at an N fertilizer rate of 60 kg/fed per season exhibited the lowest LER. This suggests that intercropping cotton at 100% and sesame at 50.0% with a 75 kg N/fed fertilizer rate may be more beneficial in terms of LER compared to the system of 100% cotton + 12.5% sesame with an application of 90 kg N/fed. These findings align with Saad *et al.* (2022).

Table 6. Effect of LER of intercropping sesame with cotton as affected by the interaction between N fertilizer rates and sesame plant densities on content in the combined data across the two seasons

Treatments		LER		
		L c	**L s**	**LER**
60 kg N/fed	100% cotton + 12.5% sesame	0.74	0.13	0.87
	100% cotton + 25.0% sesame	0.79	0.22	1.02
	100% cotton + 37.5% sesame	0.82	0.36	1.18
	100% cotton + 50.0% sesame	0.87	0.45	1.32
75 kg N/fed	100% cotton + 12.5% sesame	0.95	0.14	1.08
	100% cotton + 25.0% sesame	0.95	0.24	1.19
	100% cotton + 37.5% sesame	0.97	0.40	1.38
	100% cotton + 50.0% sesame	0.98	0.50	1.48
90 kg N/fed	100% cotton + 12.5% sesame	0.83	0.12	0.95
	100% cotton + 25.0% sesame	0.84	0.22	1.06
	100% cotton + 37.5% sesame	0.87	0.33	1.21
	100% cotton + 50.0% sesame	0.88	0.42	1.31

b. Economic evaluation

The data in Table 7 shows that the total income and net return for treatments combining N fertilizer rate and sesame plant densities in an intercropping system of sesame with cotton were higher compared to sole planting of cotton and sesame.

The intercropping system of 100% cotton + 50% sesame, with the application of 75 kg N/fed, resulted in the highest total income (153,284 LE) and net return (73,088 LE). On the other hand, applying an N fertilizer rate of 60 kg/fed to the intercropping system (100% cotton + 12.5% sesame) resulted in the lowest total income (107,099 LE) and net return (67,388 LE). These results indicate that the intercropping system of 100% cotton + 50% sesame with the application of 75 kg N/fed is more profitable than the other treatments and could be recommended. These findings underscore the significance of nitrogen fertilizer rates and intercropping ratios in determining the economic outcomes of cotton-sesame intercropping systems. Farmers should carefully consider these factors to increase their profits.

Table 7. Effect of economic evaluation of intercropping sesame with cotton as affected by N fertilizer rates and sesame plant densities components in the combined data across the two seasons

Treatments		Actual cottonseed yield (LE)	Actual sesame seed yield (LE)	Total income (LE)	Total cost (LE)	Net return (LE)
60 kg N/fed	100% cotton + 12.5% sesame	102250	4846	107099	67388	39712
	100% cotton + 25.0% sesame	108500	8534	117037	68763	48275
	100% cotton + 37.5% sesame	112375	13674	126052	69853	56199
	100% cotton + 50.0% sesame	119375	17094	136472	71318	65154
75 kg N/fed	100% cotton + 12.5% sesame	129750	5131	134884	70688	64196
	100% cotton + 25.0% sesame	131000	9106	140108	71463	68646
	100% cotton + 37.5% sesame	133375	15371	148749	72373	76377
	100% cotton + 50.0% sesame	134125	19157	153284	73088	80197
90 kg N/fed	100% cotton + 12.5% sesame	113375	4627	117994	72223	45772
	100% cotton + 25.0% sesame	115625	8232	123849	73118	50732
	100% cotton + 37.5% sesame	119750	12670	132413	74238	58175
	100% cotton + 50.0% sesame	121375	16136	137503	75058	62446
Sole cotton		137250	-	-	110340	26910
Sole sesame			38025	-	18925	19100

CONCLUSION

It can be concluded that the intercropping system of 100% cotton + 50% sesame with the application of 75 kg N/fed led to a decrease in the competitive pressure between cotton and sesame crops for basic growth resources and increased seed yield and quality of as well as LER and economic net return in the North Delta region of Egypt.

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ترشيد التسميد النيتروجيني المعدني وأثره على ربحية تحميل السمسم على القطن

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الملخص العربي

أجريت تجربة حقلية في محطة بحوث سخا الزراعية بمحافظة كفر الشيخ بمصر، خلال موسمي ٢٠٢٣ و٢٠٢٤. وتضمنت الدراسة ثلاثة معدلات من السماد النيتروجيني المعدني (٦٠ و٧٥ و٩٠ كجم نيتروجين/فدان) للقطن وأربع كثافات نباتية مختلفة لمحصول السمسم (١٢,٥، ٢٥,٠ ، ٣٧,٥ و٥٠,٠%). وهدفت هذه الدراسة إلى تحديد المعدل الأمثل للسماد النيتروجيني والكثافة النباتية المثلي للسمسم المحمل على القطن لزيادة إنتاجية المحاصيل المحملة وكفاءة استخدام الأرض والعائد الاقتصادي في منطقة شمال الدلتا. واتبع فى الدراسة التصميم الإحصائي، تصميم القطع المنشقة مرة واحدة في أربع مكررات. حيث تم تخصيص معدلات السماد النيتروجينى في القطعة الرئيسية، فى حين تم توزيع كثافات نبات السمسم في القطع الفرعية. هذا وقد أشارت النتائج إلى:

تم الحصول على أعلى إنتاجية بتحميل السمسم مع القطن من خلال نظام الزراعة البينية ١٠٠٪ قطن + ٥٠٪ سمسم مع اضافة ٧٥ كجم نيتروجين / فدان. وذلك بزراعة القطن على ريشتي المصطبة (١٤٠ سم)، مع زراعة صف واحد من السمسم بمعدل نباتين لكل جورة على مسافة ١٥ سم بين الجور على ظهر المصطبة. وقد أدى ذلك إلى زيادة إنتاجية وجودة المحاصيل المحملة، بالإضافة إلى زيادة كفاءة استخدام الأرض والعائدات الاقتصادية.

الكلمات الدالة: التحميل، جودة البذور، معدل كفاءة استغلال الأرض والعائد الاقتصادي.