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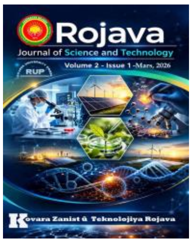

Interactive Effects of Sowing Dates and Nitrogen Splits Applications on Cotton (*Gossypium hirsutum* L.) Variety Aleppo124 Performance under Field Conditions

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Abstract

A field study was conducted to evaluate the interaction effects of sowing dates and nitrogen (N) split applications on the yield of cotton cultivar Upland Aleppo 124 under field conditions of northeastern Syria. The experiment used a split-plot design with three sowing dates (April 30, May 15, and May 30) and four nitrogen application schedules (single dose to four split doses of 250 kg N ha⁻¹). All data were subjected to statistical analysis using Genstat software (Version 12.1). Means were compared using the Least Significant Difference (LSD) test at P≤0.05, and the coefficient of variation (C.V.%) was determined. The April 30 sowing date significantly improved reproductive growth and key yield components, such as the reproductive-to-vegetative branch ratio (92.11%), boll weight (2.555 g), cotton seed yield (3425 kg ha⁻¹), fiber yield (2475 kg ha⁻¹), and cotton ginning rate (42.59%). The most effective N strategy was to divide the dose into three equal applications (at sowing, at the 5–6 true leaf stage, and at first flowering), which further increased boll growth and fiber productivity. The interaction between early sowing and triple N splits (D1 × T3) resulted in the highest fiber production (2969 kg ha⁻¹), indication the agronomic advantage of synchronizing fertilizer with key growth stages. The results of this study highlight the efficacy of integrated nutrient timing in optimizing cotton yield, improving nitrogen use efficiency, and mitigating environmental impact, thereby demonstrating a sustainable approach for semi-arid cotton production.

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Rojava Journal of Science and Technology

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1. Introduction

Cotton (*Gossypium* sp.) is a versatile crop that is cultivated for both fiber and oil production (Ali *et al., 2019*), and it is one of the most important fiber crops in the world, originally cultivated in tropical regions. Cotton is widely used in various industries, including industrial, food, and fodder applications, in the form of raw cotton, ginned cotton, or seeds. Cotton is a important source of employment in agriculture and industry and plays a vital role in the economies of major producing countries such as the United States, Egypt, India, and Syria, and for this reason it has earned the nickname "white gold", as the main use of cotton is in spinning and weaving to produce fabrics for human consumption (Ashraf *et al., 2015*). In Syria, cotton is a strategic crop that is considered the main agro-industrial commodity in terms of production value. It has the third largest share in domestic production after oil and wheat, and accounts for 15% of Syria's total agricultural exports. The area under cotton cultivation in Syria was approximately 172,000 hectares in 2010 but decreased to 34,300 hectares in 2019 and to 29,300 hectares in 2021. In 2024, the area under cultivation was estimated at 14,419 hectares, with a production of 0.01147 million metric tons and an average yield of about 3,344 kg ha^{-1} (Annual Agricultural Statistical Group, 2023). Among the key factors affecting cotton productivity, nitrogen management and sowing time are particularly critical. Nitrogen (N) is a critical nutrient for cotton growth and fiber quality; however, its excessive or improper use can lead to excessive vegetative growth, delayed boll maturity, and environmental degradation through nitrate leaching. Optimizing nitrogen timing is essential to improving nitrogen use efficiency (NUE) and maintain yield without compromising sustainability. Similarly, sowing date affects seed germination, plant vigor, boll formation, and coordination with climatic conditions. Early sowing has been shown to increase yield by maximizing the duration of the vegetative and reproductive stages, reducing pest pressure, and avoiding high-temperature stress during critical growth periods.

Nitrogen (N) fertilization is a critical determinant of cotton growth and productivity, with optimal application rates varying according to inherent soil characteristics and fertility levels. However, exceeding the physiological threshold of nitrogen, particularly during the budding stage, can elevate the position of the first reproductive branch and induce excessive vegetative growth. This imbalance often leads to a reduction in the number of reproductive branches, delays in boll maturation and opening, and ultimately, a decline in economic yield (Wu *et al.,* 2022). As a macro-nutrient required in larger quantities than most others, nitrogen plays an indispensable role in shaping the growth, productivity, and fiber quality of cotton (Khan *et al.,* 2017a, b, c).

However, excessive nitrogen application can prolong crop maturation, reduce productivity, and lower nitrogen use efficiency (NUE), while also contributing to environmental pollution (Khan et al., 2021; Kumar *et al.,* 2022; Wang *et al.,* 2022). These negative outcomes are partly attributable to the fact that cotton's nutrient requirements vary significantly across growth stages (Irish and Glen, 2020). Nitrogen demand is particularly high during early flowering but decreases in later stages (Liu *et al.,* 2022). Research indicates that moderate nitrogen application before flowering can enhance root growth (Zhu *et al.,* 2021), with biomass typically peaking during the flowering stage itself (Chen *et*

al., 2021). Despite this, farmers often rely heavily on nitrogen fertilizers to boost yields, a practice that can inadvertently compromise fiber yield and quality. Therefore, optimizing both the dose and timing of nitrogen application is crucial for enhancing NUE, mitigating nitrate (NO_3^-) pollution, and increasing farm profitability (Shah *et al.,* 2022).

In conjunction with nitrogen management, sowing time also exerts a significant influence on the agronomic and physiological traits of cotton. Selecting the most suitable sowing date allows farmers to synchronize critical growth stages with optimal environmental conditions, such as favorable temperatures for germination, seedling emergence, and subsequent development. This synchronization promotes the establishment of robust plants and supports a balanced progression of vegetative and reproductive growth (Khan *et al.,* 2020; Raza *et al.,* 2020).

Selecting an optimal sowing date can help cotton crops avoid peak periods of agricultural pest activity, thereby reducing the need for excessive chemical pesticide applications. This approach promotes sustainable integrated pest management, significantly lowers agricultural production costs, and minimizes soil contamination (Musa *et al.,* 2014). Beyond pest management, sowing time directly influences productivity; for instance, sowing in early May has been shown to increase seed cotton yield by 45% compared to late sowing in June, with concomitant improvements in economic yield components such as seed cotton and fiber (Farid *et al.,* 2017). Similarly, Jamro *et al.* (2017) reported that cotton planted on May 1 exhibited a higher net ginning rate than later-sown crops.

The optimization of sowing date is widely recognized as crucial for maximizing cotton productivity in a given region. Appropriate early sowing generally leads to increased flower formation, a greater number of open bolls, and higher seed cotton productivity compared to delayed sowing (Arshad *et al.,* 2007). Recent research supports this, with cotton sown on April 15 demonstrating superior performance, achieving an average plant height of approximately 127.93 cm, around 47 bolls per plant, a seed cotton weight of roughly 130.67 g per plant, and a seed cotton yield of 3,586.1 kg ha^{-1}. In contrast, cotton sown on subsequent dates (May 1, May 15, June 1, and June 15) showed progressively lower performance across all measured traits, with each two-week delay resulting in a consistent decline (Wahid *et al.,* 2024). This body of research confirms that sowing time fundamentally influences plant architecture, including plant height and branching patterns, as well as boll development, fiber quality, and overall productivity (Wang *et al.,* 2019).

Considering these findings, the present study was conducted with the objective of identifying agronomic practices that enhance cotton yield, fiber quality, and nitrogen efficiency under local field conditions.

2. Materials and methods

2.1. Plant Material and Study Location:

The experiment was conducted at the Agricultural Scientific Research Center in Qamishli, northeastern Syria (Rojava), during two consecutive growing seasons. The study area is characterized by a semi-arid Mediterranean climate, with hot summers and limited, irregular rainfall. The soil had a loam-texture and prepared

Rojava Journal of Science and Technology

2026, VOL. 2, No 1, [127-142]

by two perpendicular plows to a depth of 30–35 cm, followed by leveling and opening of irrigation channels. The crop under study was *Gossypium hirsutum L.* (*G. hirsutum* L.) cultivar Aleppo 124, a hybrid developed from a cross between Zambia and Aleppo 1/33 and published by the General Organization for Seed Multiplication in Syria (Cotton Research Department, 2021).

2.2. The tests studied are as follows

Main plots: Sowing dates: D_1: April 30, D_2: May 15 and D_3: May 30.

Sub-plots: Nitrogen application schedules (250 kg N ha^{-1}): **T_1**: Full dose at sowing, **T_2**: Two equal doses at sowing and 5–6 true leaf stage, **T_3**: Three equal doses at sowing, 5–6 true leaf stage, and onset of first flowering, **T_4**: Four equal doses at sowing, 5–6 true leaf stage, onset of first flowering, and mid-flowering. Each experimental unit consisted of five rows 5 m in length, with 75 cm between rows and 30 cm between plants on rows.

2.3. Crop Management

Before sowing, phosphorus (200 kg P_2O_5 ha^{-1}) and potassium (200 kg K_2O ha^{-1}) fertilizers were applied uniformly and based on soil test recommendations. Nitrogen fertilizer (urea, 46% N) was applied according to the designated treatments. Seeds were sown manually and at the two-leaf stage, thinning was performed to achieve uniform plant density. Irrigation, weeding, pest control, and other agronomic practices were carried out uniformly in all plots. Special attention was paid to preventing water or nutrient stress during critical stages of growth.

2.4. Investigated traits

The following agronomic and performance traits were recorded from 10 plants randomly selected from each plot:

- Ratio of reproductive to vegetative branches (%)
- Boll weight (g $boll^{-1}$)
- Seed cotton yield (kg ha^{-1})
- Fiber yield (kg ha^{-1})
- Ginning rate (%)

2.5. Statistical analysis

The experiment was laid out in a randomized complete block design (RCBD) with three replications. All collected data were subjected to analysis of variance (ANOVA) using GenStat software (Version 12.1) to evaluate the significance of main effects and their interactions. Treatment means were compared using Fisher's protected least significant difference (LSD) test at a 5% probability level. Additionally, Pearson's correlation coefficients were computed to determine the relationships among key agronomic and yield traits. The coefficient of variation (CV%) was also calculated for each parameter to assess the precision and reliability of the experiment.

3. Results

3.1. Ratio of Reproductive to Vegetative Branches (%)

The ratio of reproductive to vegetative branches was significantly ($P < 0.05$) the highest (92.11%) for early sowing was recorded on 30 April (D_1), followed by 15 May (81.55%), and 30 May (75.71%). Among nitrogen treatments, the three-split application (T_3) achieved the highest ratio

(82.30%), although the difference between T_3 and T_4 was not statistically significant (Table 1). When considering the combined interaction among growing seasons, sowing dates, and nitrogen fertilizer application schedules, the highest statistically significant mean ratio of reproductive to vegetative branches was observed in the first season for the first sowing date (D1) with the third (T3), fourth (T4), second (T2), and first (T1) nitrogen application schedules, with no significant differences among them (99.34%, 99.29%, 99.28%, and 99.26%, respectively). The lowest ratio was recorded in the second season for the third sowing date (D3) with the fourth (T4) and second (T2) schedules, with no significant differences between them (71.69% and 73.21%, respectively) (Table 1).

Table 1: Effects of Sowing Date and Nitrogen Split Application on Reproductive-to-Vegetative Branch Ratio (%) of Aleppo 124 Cotton.

Sowing Date	Nitrogen Application Schedule	2023 Season	2024 Season	Overall Mean of sowing date
April 30 (D1)	T1 (Single dose)	99.26[a]	85.39 [bc]	92.325
	T2 (2 splits)	99.28 [a]	85.88 [b]	92.58
	T3 (3 splits)	99.34 [a]	83.91 [bcde]	91.625
	T4 (4 splits)	99.29 [a]	84.56 [bcd]	91.925
Mean (D1)	-	**99.26**	**84.94**	**92.11 A**
May 15 (D2)	T1	82.51 [bcdefg]	83.33 [bcdef]	82.92
	T2	83.15 [bcdef]	81.97 [bcdefg]	82.56
	T3	79.35 [fghij]	80.12 [efgh]	79.735
	T4	80.72 [defg]	81.28 [defg]	81
Mean (D2)	-	**81.43**	**81.67**	**81.55 B**
May 30 (D3)	T1	79.63 [fghi]	75.69 [ijkl]	77.66
	T2	78.81 [ghij]	73.21 [kl]	76.01
	T3	75.31 [jkl]	75.87 [ijk]	75.59
	T4	76.27 [hijk]	71.69 [l]	73.98
Mean (D3)	-	**77.51**	**74.12**	**75.81 C**
Overall Mean of fertilization	T1	84.30 **A**		
	T2	83.72 **AB**		
	T3	82.31 **B**		
	T4	82.30 **B**		
Overall Mean of growing season		**Season 2023**	**Season 2024**	
		81.26 **A**	80.24 **A**	

T1: Full dose at sowing, **T2**: Two equal splits (sowing + 5–6 true leaf stage), **T3**: Three equal splits, (sowing + 5–6 true leaf stage + first flowering), **T4**: Four equal splits (sowing + 5–6 true leaf stage + first flowering + mid-flowering).

Variable	Sowing dates (S)	Fertilization Schedules(T)	Seasons (S)	(D*T)	(D*S)	(T*S)	(D*T*S)
LSD (0.05)	**1.464**	**1.691**	**1.195**	**2.928**	**2.070**	**2.391**	**4.141**
CV%	**3.0**						

3.2. Boll Weight (g boll^{-1})

The highest mean of boll weight (2.555 g) was significantly recorded for April 30 sowing (D_1), followed by May 15 (2.306 g), with the lowest in May 30 (1.785 g). Delaying sowing by 15 and 30 days led to 9.74% and 30.14% reductions in boll weight, respectively (Table 2). Nitrogen applied in three or four splits (T_3 and T_4) resulted in greater boll weights than single-dose applications, due to improved nutrient uptake during boll development. Analysis of the three-way interaction among sowing date, nitrogen schedule, and growing season revealed that the highest mean boll weights were recorded during the first season. Specifically, D1 with T3 (3.648 g), and D2 with both T3 and T4 (3.414 g and 3.141 g, respectively) produced the highest values and were statistically at par with one another. Conversely, the lowest boll weights were observed in the second season, with D3T1 (1.252 g), D3T2 (1.368 g), and D2T1 (1.413 g) forming a statistically similar group at the lower end of the range (Table 2).

Table 2: Effects of Sowing Date and Nitrogen Split Application on Seed Cotton Weight per Boll of Aleppo 124 Cotton.

Sowing Date	Nitrogen Application Schedule	2023 Season	2024 Season	Overall Mean of sowing date
April 30 (D1)	T1 (Single dose)	2.913 bcd	1.709 fgh	2.311
	T2 (2 splits)	2.942 bcd	2.028 efg	2.485
	T3 (3 splits)	3.648 a	2.115 ef	2.8815
	T4 (4 splits)	3.048 bc	2.035 efg	2.5415
Mean (D1)		**3.137**	**1.972**	**2.555 A**
May 15 (D2)	T1	2.840 cd	1.413 h	2.1265
	T2	2.926 bcd	1.550 gh	2.238
	T3	3.414 ab	1.584 fgh	2.499
	T4	3.141 abc	1.577 fgh	2.359
Mean (D2)		**3.080**	**1.531**	**2.306 B**
May 30 (D3)	T1	1.588 fgh	1.252 h	1.42
	T2	1.636 fgh	1.368 h	1.502
	T3	2.976 bc	1.553 gh	2.2645
	T4	2.413 de	1.494 gh	1.9535
Mean (D3)		**2.153**	**1.417**	**1.785 C**
Overall Mean of fertilization	T1	1.953 **C**		
	T2	2.075 **BC**		
	T3	2.548 **A**		

Sowing Date	Nitrogen Application Schedule	2023 Season	2024 Season	Overall Mean of sowing date
	T4	2.285 **B**		
Overall Mean of growing season		**Season 2023**		**Season 2024**
		2.79 **A**		1.640 **B**

T1: Full dose at sowing, **T2**: Two equal splits (sowing + 5–6 true leaf stage), **T3**: Three equal splits, (sowing + 5–6 true leaf stage + first flowering), **T4**: Four equal splits (sowing + 5–6 true leaf stage + first flowering + mid-flowering).

Variable	Sowing dates (S)	Fertilization Schedules(T)	Seasons (S)	(D*T)	(D*S)	(T*S)	(D*T*S)
LSD (0.05)	**0.1911**	**0.2206**	**0.1560**	**0.3821**	**0.2702**	**0.3120**	**0.5404**
CV%	**14.9**						

3.3. Seed Cotton Yield (kg ha⁻¹)

Early sowing on April 30 (D_1) produced significantly the highest yield (3425 kg ha^{-1}), with a 24.26% and 83.73% yield decline observed for the May 15 and May 30 sowings, respectively (Table 3). Among nitrogen treatments, T_3 (three-way split) resulted in the highest yield (2627 kg ha^{-1}), significantly outperforming the single-dose application (T_1). The interaction of $D_1 \times T_3$ produced the highest combined mean yield (4394 kg ha^{-1} in the first season). The interaction between early planting and split nitrogen applications consistently leads to superior yields, with the first growing season typically outperforming subsequent seasons due to better plant health and reduced pest infestations. The first growing season yielded the highest statistically significant mean seed cotton yield (3427 kg ha^{-1}) compared to the second season (957 kg ha^{-1}) (Table 3).

Table 3: Effects of Sowing Date and Nitrogen Split Application on Seed Cotton Yield (kg ha⁻¹) of Aleppo 124 Cotton.

Sowing Date	Nitrogen Application Schedule	2023 Season	2024 Season	Overall Mean of sowing date
April 30 (D1)	T1 (Single dose)	4584 ^{bc}	1336 ^{ef}	**2960**
	T2 (2 splits)	5080 ^{b}	1432 ^{ef}	**3256**
	T3 (3 splits)	5800 ^{a}	2029 ^{e}	**3914.5**
	T4 (4 splits)	5185 ^{ab}	1952 ^{e}	**3568.5**
Mean (D1)		**5162**	**1687.1**	**3425 A**
May 15 (D2)	T1	3415 ^{d}	523 ^{ghi}	**1969**
	T2	4049 ^{cd}	765 ^{fghi}	**2407**
	T3	5144 ^{ab}	1083 ^{fgh}	**3113.5**
	T4	4867 ^{b}	908 ^{fghi}	**2887.5**
Mean (D2)		**4369**	**819.8**	**2594 B**

Sowing Date	Nitrogen Application Schedule	2023 Season	2024 Season	Overall Mean of sowing date
May 30 (D3)	T1	433 hi	215 i	**324**
	T2	498 ghi	315 i	**406.5**
	T3	1205 fg	500 ghi	**852.5**
	T4	862 fghi	428 hi	**645**
Mean (D3)	-	**750**	**364.6**	**557 C**
Overall Mean of fertilization	T1	1751 **B**		
	T2	2023 **B**		
	T3	2627 **A**		
	T4	2367 **A**		
Overall Mean of growing season		**Season 2023**		**Season 2024**
		3427 A		**957 B**

T1: Full dose at sowing, **T2**: Two equal splits (sowing + 5–6 true leaf stage), **T3**: Three equal splits, (sowing + 5–6 true leaf stage + first flowering), **T4**: Four equal splits (sowing + 5–6 true leaf stage + first flowering + mid-flowering).

Variable	Sowing dates (S)	Fertilization Schedules(T)	Seasons (S)	(D*T)	(D*S)	(T*S)	(D*T*S)
LSD (0.05)	**251.5**	**290.4**	**205.3**	**503.0**	**355.6**	**410.7**	**711.3**
CV%	**19.8**						

3.4. Fiber Yield (kg ha⁻¹)

Fiber yield followed similar trends as seed cotton yield. The highest fiber yield was obtained from early sowing (D_1: 2475 kg ha^{-1}), followed by D_2 (1920 kg ha^{-1}), and D_3 (363 kg ha^{-1}). A delay of 15 days from the optimal sowing date (April 30) resulted in a 22.42% decrease in fiber yield, while a 30-day delay led to an 85.33% reduction, underscoring the importance of precise sowing timing for maximizing seed cotton and fiber yield. Nitrogen applied in three equal splits (T_3) yielded the highest fiber output (1962 kg ha^{-1}), while the lowest yield was observed for the first schedule (T1) 1225 kg ha^{-1}. The interaction $D_1 \times T_3$ achieved a peak fiber yield of 2969 kg ha^{-1}, and 4394 kg ha^{-1} in the first growing season (Table 4). For the three-way interaction, the maximum fiber yield (4394 kg ha^{-1}) occurred in season one with D1T3. The minimum yields, all statistically similar, were obtained in season two from D3T1, D3T2, and D3T4, averaging 116, 175, and 241 kg ha^{-1}, respectively (Table 4).

Table 4: Effects of Sowing Date and Nitrogen Split Application on Fiber Yield (kg ha⁻¹) of Aleppo 124 Cotton.

Sowing Date	Nitrogen Application Schedule	2023 Season	2024 Season	Overall Mean of sowing date
April 30 (D1)	T1 (Single dose)	3004 cd	968 fgh	1986
	T2 (2 splits)	3615 b	1122 efg	2369

Sowing Date	Nitrogen Application Schedule	2023 Season	2024 Season	Overall Mean of sowing date
	T3 (3 splits)	4394^{a}	1544^{e}	2969
	T4 (4 splits)	3746^{b}	1404^{ef}	2575
Mean (D1)	-	**3690**	**1259.6**	**2475 A**
May 15 (D2)	T1	2588^{d}	416^{ijkl}	1502
	T2	3103^{c}	564^{hijk}	1834
	T3	3787^{b}	809^{ghi}	2298
	T4	3403^{bc}	688^{ghij}	2046
Mean (D2)	-	**3220**	**619.4**	**1920 B**
May 30 (D3)	T1	256^{jkl}	116^{l}	186
	T2	337^{jkl}	175^{kl}	256
	T3	881^{gh}	357^{jkl}	619
	T4	541^{hijkl}	241^{kl}	391
Mean (D3)	-	**504**	**222.3**	**363 C**
Overall Mean of fertilization	T1	1225 **D**		
	T2	1486 **C**		
	T3	1962 **A**		
	T4	1671 **B**		
Overall Mean of growing season		**Season 2023**		**Season 2024**
		2471.16 A		**700.4 B**

T1: Full dose at sowing, **T2**: Two equal splits (sowing + 5–6 true leaf stage), **T3**: Three equal splits, (sowing + 5–6 true leaf stage + first flowering), **T4**: Four equal splits (sowing + 5–6 true leaf stage + first flowering + mid-flowering).

Variable	Sowing dates (S)	Fertilization Schedules(T)	Seasons (S)	(D*T)	(D*S)	(T*S)	(D*T*S)
LSD (0.05)	**155.6**	**179.6**	**127.0**	**311.2**	**220.0**	**254.1**	**440.0**
CV%	**16.9**						

3.5. Ginning Rate (%)

The highest ginning rate was observed with April 30 sowing (42.59%), with notable declines for May 15 (41.15%) and May 30 (38.37%). T_3 nitrogen treatment produced the highest ginning rate (42.79%), followed by T_4, T_2, and T_1. The highest statistically significant mean ginning rate was observed in the first season for the first sowing date (D1) with the third (T3) nitrogen application schedule (44.11%), while the lowest was recorded in the second season for the third sowing date (D3) with the first (T1) nitrogen application schedule (35.28%) in the combined interaction of sowing dates, nitrogen fertilizer application schedules, and growing seasons (Table 5).

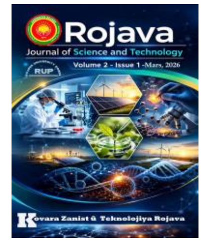

Table 5: **Effects of Sowing Date and Nitrogen Split Application on Ginning Rate (%) of Aleppo 124 Cotton.**

Sowing Date	Nitrogen Application Schedule	2023 Season	2024 Season	Overall Mean of sowing date
April 30 (D1)	T1 (Single dose)	39.64 ^{def}	42.07 ^{abcd}	40.855
	T2 (2 splits)	41.86 ^{abcd}	43.99 ^{a}	42.925
	T3 (3 splits)	44.11 ^{a}	43.20 ^{abc}	43.655
	T4 (4 splits)	43.95 ^{a}	41.85 ^{abcd}	42.9
Mean (D1)	-	**42.39**	**42.78**	**42.59 A**
May 15 (D2)	T1	40.12 ^{cdef}	41.34 ^{abcde}	40.73
	T2	40.38 ^{bcde}	41.72 ^{abcde}	41.05
	T3	42.47 ^{abcd}	42.75 ^{abcd}	42.61
	T4	41.58 ^{abcde}	41.12 ^{abcde}	41.35
Mean (D2)	-	**41.14**	**41.73**	**41.15 B**
May 30 (D3)	T1	37.08 ^{fghk}	35.28 ^{k}	36.18
	T2	40.18 ^{cdef}	35.75 ^{hk}	37.965
	T3	42.33 ^{abcd}	41.83 ^{abcd}	42.08
	T4	38.54 ^{efgh}	35.98 ^{ghk}	37.26
Mean (D3)	-	**39.53**	**37.21**	**38.37 C**
Overall Mean of fertilization	T1	39.76 **B**		
	T2	40.65 **B**		
	T3	42.79 **A**		
	T4	**40.50B**		
Overall Mean of growing season		**Season 2023**	**Season 2024**	
		41.02 A	**40.57 B**	

T1: Full dose at sowing, **T2**: Two equal splits (sowing + 5–6 true leaf stage), **T3**: Three equal splits, (sowing + 5–6 true leaf stage + first flowering), **T4**: Four equal splits (sowing + 5–6 true leaf stage + first flowering + mid-flowering).

Variable	Sowing dates (S)	Fertilization Schedules(T)	Seasons (S)	(D*T)	(D*S)	(T*S)	(D*T*S)
LSD (0.05)	**1.127**	**1.302**	**0.420**	**2.255**	**1.594**	**1.841**	**3.189**
CV%	**4.7**						

3.6. Correlation Analysis

Correlation analysis revealed that the reproductive-to-vegetative branch ratio was positively and significantly associated with boll weight (r = 0.74), seed cotton yield (r = 0.49*), and fiber yield (r = 0.70 and 0.69), suggesting its utility as a key indicator of yield performance (Table 6). Furthermore, boll weight exhibited a strong positive correlation with both seed cotton yield (r = 0.85) and fiber yield (r = 0.84), underscoring its critical role as a primary yield determinant. The highly significant positive correlation between seed cotton yield and fiber yield (r = 0.99) further emphasizes the importance of optimizing planting and fertilization practices to maximize overall cotton productivity (Table 6).

Table 6: Simple Correlation Relationships Between Various Studied Traits as Means for Two Growing Seasons.

Trait	Ratio RB:VB	WSBP	SYW	FYW	GR
Ratio RB:VB	-				
WSBP	0.49*	-			
SYW	0.70**	0.85**	-		
FYW	0.69**	0.84**	0.99**	-	
GR	0.33	0.27	0.28	0.35	

Ratio RB:VB: Ratio of reproductive to vegetative branches, WSBP: Weight of a single boll per plant, SYW: Seed yield weight, FYW: Fiber yield weight, GP: Ginning rate.

4. Discussion

The phenological development and resultant productivity of cotton are profoundly influenced by the intricate interplay between genotype, environmental conditions, and agronomic management. This study elucidates the significant effects of sowing date and nitrogen splitting on key agronomic traits, yield components, and fiber quality, with findings that are largely consistent with established physiological principles and previous research.

The developmental trajectory of the cotton plant, particularly the balance between vegetative and reproductive growth, was markedly influenced by sowing time. The substantially higher ratio of reproductive to vegetative branches observed with the earliest sowing date (D1, April 30) at 92.11%, compared to later plantings (D2 and D3), can be ascribed to more favorable ambient conditions during the critical early growth phase. These conditions likely promoted an earlier transition to reproductive development and optimized assimilate partitioning towards fruiting sites, curtailing excessive vegetative proliferation (Ali *et al.,* 2009; Bange *et al.,* 2008). Conversely, delayed sowing exposed the crop to sub-optimal environmental cues, which can disrupt this balance and result in a lower proportion of reproductive branches. Nitrogen management further modulated this balance. The superior ratios observed with a full dose at sowing (T1) and two equal splits (T2), relative to more frequent splits (T3 and T4), suggest that a concentrated, early-season nitrogen supply supports foundational vegetative growth without unduly postponing the initiation of fruiting. In contrast, highly fractionated applications may inadvertently prolong vegetative growth at the expense of reproductive branch development in specific interactions, underscoring the importance of synchronizing nitrogen availability with plant demand.

Boll weight, a direct determinant of yield, demonstrated significant sensitivity to both management practices and biotic stress. The significant decrease in mean seed cotton weight per boll with delayed sowing corroborates the findings of Copur *et al.* (2019), who reported reductions from approximately 4.75 g to 4.67 g with later planting. This decline is physiologically attributable to the exposure of the boll setting, formation, and filling phases to supra-optimal temperatures, which can impair photosynthetic efficiency and curtail the supply of assimilates to developing bolls. The data further revealed that applying nitrogen in four equal split doses (T3) produced the highest mean boll weight for the Aleppo 124 cultivar, a result that aligns with the findings of Almahasneh *et al.* (2023) in the Al-Ghab region and reinforces the superiority of split application strategies over a single basal dose, as also reported by Hassan *et al.* (2024). The enhanced performance under D1 likely reflects improved synchrony between plant developmental stages and prevailing environmental conditions. The pronounced inter-annual variation, with a mean boll weight of 2.790 g in the first season versus 1.640 g in the second, highlights the overriding impact of biotic constraints. The substantial reduction in the second season was directly linked to infestation by the cotton bollworm (*Helicoverpa armigera*), which diminished the number of open bolls and, consequently, the mean boll weight, thereby cascading negatively on seed cotton yield, fiber yield, and ginning rate.

The cumulative effects of these factors were ultimately manifested in seed cotton yield. The progressive decline in yield with delayed sowing is a well-documented phenomenon, resulting from suboptimal temperatures and truncated boll development periods during critical reproductive stages. Early sowing typically extends the growing season, facilitating greater leaf area development, enhanced dry matter accumulation, and increased flower production, all of which contribute to higher boll formation and final yield (Arain *et al.,* 2001; Kuchinda *et al.,* 2002; Mahmood-ul-Hassan *et al.,* 2003; Bozbek *et al.,* 2006; Bange *et al.,* 2008). Delayed planting, conversely, can curtail both vegetative and reproductive branching, delay flowering, and expose the crop to heightened pest pressure and unfavorable terminal conditions, ultimately limiting the time available for boll maturation (Gormus and Yucel, 2002). The seed cotton yields recorded in this study, ranging from 1932.93 to 4154.64 kg ha^{-1} depending on planting time, are consistent with the range reported by multiple authors for similar environments (Copur *et al.,* 2019; Sharif *et al.,* 2020; Wahid *et al.,* 2024). In the specific context of northeastern Syria, delayed sowing coincides with elevated temperatures in June and July, which can suppress the photosynthetic rate of cotton, a C3 plant, and thus reduce dry matter accumulation (Arain *et al.,* 2001; Kuchinda *et al.,* 2002; Mahmood-ul-Hassan et al., 2003; Bozbek *et al.,* 2006; Bange *et al.,* 2008). In terms of nitrogen management, the data affirms that split applications enhance nutrient use efficiency and yield potential compared to a single application (Kilanie *et al.,* 2016; Hakoomat *et al.,* 2011), with the three-way split (T3) proving particularly effective. The superior yield in the first season was a direct function of the higher number of open bolls per plant and greater boll weight, parameters that were severely compromised by bollworm infestation in the second season.

Fiber yield, the primary economic product, mirrored the trends observed in seed cotton yield. The sharp reduction in fiber yield with delayed sowing underscores the adverse impact of thermal stress during boll filling on both fiber initiation and elongation, processes highly dependent on sustained photosynthetic activity. These findings reinforce the conclusions of Basal *et al*. (2018) regarding the critical importance of optimal sowing date selection for maximizing not only productivity but also the quality and economic viability of cotton cultivation. The lower fiber yield in the second season is again predominantly explained by the bollworm infestation and the resultant decline in boll retention and development. The superior fiber yield achieved with the four-way split nitrogen application (T3) is in close agreement with the results of Almahasneh *et al.* (2023), who reported the highest significant mean fiber yield (2274 kg ha^{-1}) for the Aleppo 124 cultivar under a similar four-split regime in the Al-Ghab region.

The ginning rate, a key quality and economic trait, was also significantly influenced. The observed variation, with the highest rate for early sowing (e.g., 36.02% for April 15 as reported by Wahid *et al*., 2024) and the lowest for very late sowing (34.77%), reflects the dependence of boll maturity and uniform fiber development on an adequate, stress-free growing period. The higher ginning efficiency associated with early sowing and the T3 nitrogen treatment in this study is attributed to improved boll maturation and more complete fiber differentiation, supporting their adoption as practices that enhance both fiber quality and economic return in the Al-Ghab region, consistent with Almahasneh *et al.* (2023).

In synthesis, the combination of early sowing (D1) and a three-way split nitrogen application (T3) consistently yielded the highest values across the majority of agronomic and yield parameters assessed. This synergistic interaction underscores a fundamental principle of crop physiology: optimizing the alignment between crop phenology, nutrient availability, and environmental suitability. By promoting efficient nitrogen use, maximizing the allocation of biomass to reproductive structures, and ensuring favorable conditions for boll and fiber development, this integrated management strategy offers a robust and sustainable pathway for cotton intensification under the semi-arid conditions characteristic of northeastern Syria.

5. Conclusion

5.1. Early sowing (April 30) combined with three equal nitrogen splits significantly improved yield and fiber quality of Aleppo 124 cotton under field conditions in northeastern Syria. This integrated approach optimizes input efficiency, enhances economic returns, and promotes sustainable cotton intensification, while Delayed sowing (May 15 and May 30) led to a statistically significant decline in the growth and productivity of the Aleppo 124 cotton due to a shortened growth period and unfavorable environmental conditions**.**

5.2. Early sowing enabled optimal plant establishment under favorable temperatures, leading to balanced vegetative and reproductive growth, increased boll setting, and enhanced fiber development.

5.3. Applying nitrogen in multiple splits ensured that nutrient availability was synchronized with crop demand at key developmental stages, thereby enhancing nitrogen use efficiency and maximizing yield.

5.4. The significant interaction between sowing date and nitrogen application schedules underscores the importance of integrated management practices to achieve optimal cotton productivity.

5.5. Despite these positive outcomes, environmental factors such as rainfall variability, temperature fluctuations, and pest pressures remain challenges to cotton production, necessitating the development of region-specific, climate-resilient agronomic recommendations.

5.6. Overall, adopting these integrated strategies promotes sustainable intensification by increasing productivity while reducing the environmental footprint of cotton cultivation. Future research should focus on incorporating optimized water management and integrated pest management practices alongside these sowing and fertilization strategies to develop comprehensive and climate-smart cotton production packages suitable for semi-arid regions.

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