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Response of Cotton Lint Yield, Quality and Nitrogen Efficiency Indices to Nutrient Systems in Direct Seeding and Transplanting Systems

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IN ARID and semiarid regions, high temperatures often hinder cotton germination and establishment. Transplanting cotton can mitigate these challenges. This study investigated the effects of different nutrient systems on cotton lint yield, quality, and nitrogen use efficiency under direct seeding and transplanting conditions. A split-plot design with three replications was employed, with four fertilizer treatments (organic, chemical, combined, and control) as the main plot and two planting methods (transplanting and direct seeding) as the sub-plot. The combined chemical and organic fertilizer treatment significantly increased boll number per plant (88.9%) and boll weight (131%) compared to the control. Organic fertilizer treatment led to a 42.3% improvement in fiber percentage. Transplanting in the combined nutrient system enhanced lint yield by 18.5% and 20% in the first and second years, respectively, compared to direct seeding. Similarly, transplanting with organic fertilizer increased lint yield by 18.5% and 25% in the respective years. Chemical fertilizers exhibited the highest agronomic, recovery, and utilization efficiencies for nitrogen in both planting methods. The results suggest that combining organic matter with chemical fertilizers and adopting a transplanting method can significantly boost cotton fiber and lint yield while potentially reducing chemical fertilizer inputs by 50%.

Keywords: Industrial plants, Integrated nutrient management, Lint yield, Planting method.

Introduction

Cotton (*Gossypium hirsutum* L.) is a globally significant crop, cultivated in over 100 countries with an annual production of approximately 25 million tons (Khan *et al.*, 2020). Its oil, protein, and fiber are essential for human and animal nutrition, and the textile industry. Cotton contributes 6% of the world's protein supply and is the primary source of natural fibers, accounting for 80% of the market (Townsend, 2020). China, India, and the United States are the leading cotton producers, collectively representing 55% of global production. Iran ranks as the 23rd largest cotton producer worldwide (Anonymous, 2023).

The duration of the growing season significantly impacts cotton yield. Transplanting, as an alternative to direct seeding, can extend the growing period, particularly when planting is delayed due to late wheat or barley harvest. Research indicates that transplanting can boost cotton yield by 38% compared to direct seeding, while also improving water use efficiency by 14%, accelerating maturity by 45%, and increasing lint percentage by 3.3% (Khajeh Mozaffari *et al.*, 2019).

However, the impact of transplanting on yield and water use varies based on planting date. Early planting (June 15th) resulted in accelerated maturity by 43 to 49 days through transplanting, but yield and water requirements remained unaffected. On the optimal planting date (July 1st), transplanting expedited maturity by 27 to 38 days without significantly influencing yield or water consumption. Conversely, late planting (July 30th) demonstrated a significant increase in yield (361 g.m-2) with transplanting, but no substantial change in irrigation needs (271 to 300 mm) (Salmani *et al.*, 2021).

The overreliance on chemical fertilizers and the concurrent disregard for organic and biological fertilizers in recent years has led to a substantial decline in soil organic matter, triggering environmental issues such as soil degradation and nutrient imbalances (Pahalvi *et al.*, 2021). Currently, integrated nutrient management in agricultural crops is viewed as an ecological approach to enhance system stability and boost production (Waqas *et al.*, 2020).

Regarding cotton's response to different fertilizer types, studies have shown that bacterial inoculation can elevate leaf nitrogen content without significantly affecting cotton yield or related

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components (GharanjikiandFallah Nosrat-abad, 2020). Solely using chemical fertilizers has been linked to decreased cotton growth and performance due to weed competition. However, reducing urea fertilizer by half and replacing it with nitroxin increased cotton yield by 61% due to more bolls per plant compared to chemical fertilizer-only treatments (Rahimizadeh, 2020).

Research on the integrated use of organic and inorganic nutrient sources with effective microorganisms on cotton growth and yield revealed that individual applications of these inputs had no impact on cotton yield or its components. Conversely, their combined use led to a 44% yield increase over the control. Applying NPK (170:85:60 kg) alongside organic materials and effective microorganisms resulted in the highest seed cotton yield (2470 kg ha−1). A similar yield (2165 kg ha−1) was obtained with the integrated use of organic materials, effective microorganisms, and half the recommended NPK (Khaliq *et al*., 2006).

A positive correlation between organic manure combined with biochar and cotton root characteristics has been documented. By enriching soil nutrients, this combination significantly influenced root architecture and physiology (Zhang *et al*., 2020).

Nitrogen uptake and use efficiency (NUE) in cotton production are significantly influenced by various agronomic factors, such as sowing dates, planting density, tillage practices, irrigation management, crop rotation, intercropping, nitrogen form, and application timing. These factors can interact with each other and environmental conditions to impact plant growth, yield, and nitrogen utilization efficiency (Balasubramanian *et al*., 2004; Congreves *et al*., 2021; Koocheki *et al*., 2015; Mooleki *et al*., 2004; Shah *et al*., 2022). Research has indicated that increasing nitrogen levels often leads to decreased agronomic and nitrogen uptake efficiency in cotton (Koocheki *et al*., 2015). By effectively managing these factors and nitrogen fertilization, it is possible to optimize nitrogen use efficiency, leading to higher yields, reduced environmental impact, and potential cost savings.

Given the growing adoption of the transplanting cultivation system in cotton production, limited research has focused on enhancing cotton productivity through different nutritional strategies within this system. This study aims to evaluate the impact of various nutrient systems on yield and yield components in both direct seeding and transplanting cotton cultivation methods.

Materials and Methods

Experiment location and climatic characteristics

This two-year study (2020-2021) was conducted in a semi-arid region of Rudab, Iran (35°37'N, 57°18'E, 1420 m). The site experienced an average annual temperature of 15.5°C and precipitation of 122 mm, as detailed in Table 1. The experiment was conducted as a split-plot design with three replications. Fertilizer treatments (chemical, organic, chemical + organic, and control) were assigned to the main plots. Planting method (transplanting or direct seeding) was applied as a sub-plot factor. Chemical fertilizer rates were determined based on soil test recommendations. Organic fertilizer, sourced from pelletized chicken manure, was applied to the respective treatments. In the combined treatment, equal amounts of chemical and organic fertilizers were used.

Table 1. Average temperature and total rainfall in growing season in two years.

Month	Minimum temperature (◦C)		Maximum temperature (◦C)		Total rainfall (mm)	
	2020	2021	2020	2021	2020	2021
January	-1.0	0.7	25.5	18.1	32.4	17.8
February	2.6	0.7	30.9	28.0	24.6	38.8
March	3.7	7.4	38.9	37.8	83.0	66.8
April	8.6	12.0	39.0	36.7	81.4	120.8
May	14.9	17.6	37.7	38.4	37.3	32.2
June	22.4	24.5	36.0	32.8	0.4	0.0
July	23.9	25.0	28.4	26.2	0.0	0.6
August	25.1	24.3	18.3	21.6	0.0	0.0
September	19.0	22.4	16.0	11.8	0.0	0.2
October	11.8	13.4	25.5	18.1	10.2	0.0
November	8.4	5.8	30.9	28.0	23.2	9.6
December	2.9	3.8	38.9	37.8	8.8	11.0

Soil sampling and land preparation

Prior to the experiment, soil samples were collected from the top 30 centimeters of the field. Various physical and chemical soil properties were determined and recorded (Table 2). Subsequently, the soil was amended with 150 kg/ha of triple superphosphate and potassium sulfate, which were thoroughly mixed into the soil. To meet the nitrogen requirement of 250 kg/ha, urea fertilizer was applied in three stages: one-third at planting and the remaining two-thirds after the first and second weedings. Additionally, chicken manure was incorporated at a rate of 3 tons/ha (Mehrandesh *et al*., 2021). The characteristics of the chicken manure used are presented in Table 3.

Each experimental plot consisted of six rows, each 50 cm wide and 4 meters long. Within each row, cotton plants were spaced at 20 cm intervals. Cotton seeds of the Varamin variety were used for the experiment. Two planting methods were employed in this study. In the transplanting method, seeds were initially sown in seedling trays within a greenhouse in early May. After a month, when seedlings reached a height of 17 cm, they were transplanted to the main field around June 1st. The seedlings, along with the surrounding soil, were carefully transferred to pre-prepared rows using a shovel. Daily irrigation was provided to the seedlings in the greenhouse for the first 30 days. In contrast, the conventional planting method involved directly sowing cotton seeds into rows using a pneumatic seeder at the same time as transplanting the seedlings. The initial irrigation was applied immediately after planting for both methods. A second irrigation was conducted 10 days later to prevent soil compaction and promote seedling growth. Thinning was performed when plants reached the 5-6 leaf stage to achieve a final plant spacing of 20 cm. Manual weed control was carried out three times during the experiment. No pesticides were applied as no pests were observed.

Table 2. Physicochemical properties of the soil at the experimental site.

Manganese	Sodium	Zinc	Copper	Iron	Phosphorus	Potash	Nitrogen	Sand	Clay	Silt	EC	$pH_{(1:5)}$
(mg kg^{-1})					PPm		(%)	%			(dS m^{-1})	
5.10	21	0.50	0.65	3.01	7.6	200	0.074	24	20	56	2.2	7.5

Table 3. Specifications of plate poultry manure used in this experiment.

Organic content (%)	Nitrogen (%)	Phosphorus (%)	Potash (%)	Sulfur (%)	Iron (ppm)	Magnesium (ppm)	Zinc (ppm)
33	4	3	4	5	400	600	900

Measurement of yield, yield component and lint quality:

Yield components were determined by randomly selecting five plants from the middle rows of each plot and counting the number of bolls per plant. Additionally, the average weight of 10 randomly selected bolls was measured. Seed cotton yield was harvested in a single step after approximately 90% of the bolls had opened. To calculate yield, a 3 m² area from the middle rows of each plot was manually cleared of marginal plants, and the remaining seed cotton was weighed.

Fiber quality parameters, including length, strength, fineness, uniformity, and elongation, were assessed using an HVI machine. A 200-gram fiber sample was prepared by rolling denim to extract the fibers for analysis at the Varamin Fiber Technology Laboratory.

Measurement of Nitrogen and Nitrogen efficiency indices

Nitrogen content was determined using the micro-Kjeldahl method as described by Nelson and Sommers (1973). Plant reproductive and vegetative organs were dried separately and ground to pass through a 1 mm sieve. Subsequently, 0.1 g of each sample was analyzed for nitrogen content. Several nitrogen use efficiency indices were calculated according to Koocheki *et al.* (2015).

Agronomic Nitrogen Use Efficiency (ANUE)

$$ANUE = \frac{Y}{Ns}$$

Y represents seed cotton yield in kg/ha, and Ns denotes the total nitrogen content in the soil plus the applied nitrogen fertilizer in kg/ha.

Nitrogen Uptake (Recovery) Efficiency (NRE)

$$NRE = \frac{N_{uptake}}{Ns}$$

N_uptake represents the quantity of nitrogen absorbed by cotton (kg/ha), calculated as the total nitrogen in the system (including fertilizer) (kg/ha).

3.2.5. Nitrogen Utilization Efficiency (NUE)

Also known as physiological, was calculated using the equation:

$$NUE = \frac{Y}{N_{uptake}}$$

Where Y represents seed cotton yield in kg.ha^{-1}

Statistical analysis

Statistical analyses were performed using SAS software (version 9.4). Means were compared using Duncan's multiple range test at the 5% significance level. Data were visualized using Excel

Results and Discussion:

Yield components

Nutrition systems significantly influenced branch number, boll number per plant, and 10-boll weight. Planting method had no impact on these yield components. However, the interaction between nutrition systems and planting method significantly affected branch number and boll number per plant. Additionally, 10-boll weight was influenced by the interaction of nutrition systems, planting method, and year (Table 4).

Table 4. Source of variation, degree of freedom, and mean square of the investigated traits of cotton affected by nutrient systems and planting method.

		Branch number	Boll number per plant	10-boll weight	Seed cotton yield	Lint percentage	Lint yield	Fiber length	Fiber uniformity	Fiber strength	Fiber micronaire
Year (Y)	1	1.02^{ns}	75.8^{ns}	26929^{*}	36910380^{ns}	1701^{*}	11256698^{*}	0.017^{ns}	0.125^{ns}	0.425^{ns}	0.002^{*}
Error 1	4	0.08	2.81	36.3	67705	22.3	47646	0.182	0.642	0.395	0.004
Nutrient system N)	3	231^{*}	655^{*}	23811^{*}	5831155^{*}	604.2^{ns}	165496^{ns}	2.77^{*}	1.93^{ns}	95.5^{*}	0.167^{ns}
Y×N	3	21.9^{**}	45.6^{ns}	2170^{**}	157915^{ns}	5.62^{ns}	40902^{ns}	0.292^{ns}	2.16^{ns}	10.3^{ns}	0.416^{ns}
Error 2	12	1.28	0.51	68.7	379511	20.3	103355	0.524	1.15	3.66	0.171
Planting (P)	1	0.19^{ns}	1.19^{ns}	34.9^{ns}	2121775^{ns}	16.6^{ns}	737103^{ns}	2.20^{**}	2.34^{**}	66.0^{**}	5.21^{*}
N×P	3	3.80^{*}	3.51^{ns}	81.9^{ns}	73297^{ns}	9.25^{ns}	7466^{ns}	1.38^{ns}	5.14^{*}	2.83^{ns}	0.050^{ns}
Y×P	1	1.69^{ns}	0.184^{ns}	36.7^{ns}	115475^{ns}	20.0^{ns}	433172^{ns}	0.001^{ns}	0.142^{ns}	1.09^{ns}	0.125^{ns}
Y×N×P	3	0.41^{ns}	1.11^{*}	54.4^{**}	959261^{**}	6.8^{ns}	434663^{**}	2.846^{ns}	0.551^{ns}	4.40^{ns}	0.216^{ns}
Error 3	16	0.437	1.95	3.47	134932	10.1	20635	1.67	2.79	2.14	0.096
CV		10.9	18.2	5.61	11.9	8.31	11.9	4.26	1.99	4.39	6.88
$\chi2$	1	3.03^{ns}	10.4^{**}	99^{**}	26.9^{*}	0.752^{ns}	3.02^{ns}	0.25^{ns}	1.75^{ns}	0.35^{ns}	1.36^{ns}

ns: not significant; (*) and (**) represent a significant difference at P<0.05 and P<0.01, respectively.

Branch number was highest in the chemical+organic treatment for both planting methods. No significant difference in branch number was observed between transplanting and direct seeding under this treatment. While a slight difference in branch number was noted between the two planting methods in the organic treatment, the transplanting method consistently produced more branches per plant than direct seeding in the control treatment (Fig. 1).

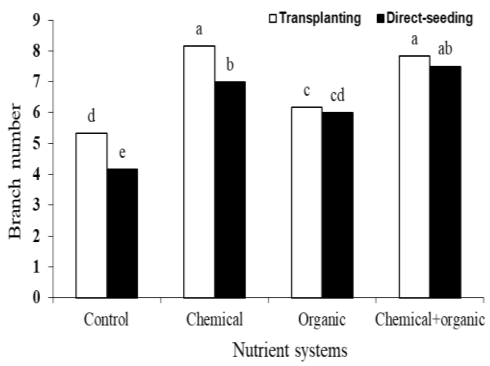

Fig. 1. Effect of nutrient systems and planting method on branch number per plant.

Cotton plants grown using the transplanting method produced significantly more bolls than those grown with direct seeding. The highest boll numbers per plant were achieved with the chemical+organic treatment in the transplanting system, followed by the chemical treatment alone, while the control treatment resulted in the lowest boll numbers for both planting methods. These findings can be attributed to earlier vegetative and reproductive growth stages in transplanted cotton, leading to reduced boll and square abscission compared to direct seeding. The transplanting method also resulted in a 46.7% increase in total boll number.

A robust root system in transplanted seedlings enhanced nutrient and water uptake, promoting earlier flowering and fruiting and consequently, more bolls. Integrated fertilizer treatments significantly increased boll number compared to the control, due to the combined effects of readily available chemical nutrients and the sustained release of nutrients from organic fertilizers. This optimized nutrient supply contributed to increased photosynthesis, plant growth, and boll retention.

Previous research has also shown that improved nutrient availability and root development can lead to higher boll numbers. Cytokinin levels, influenced by fertilizer application, play a role in promoting side shoot development and consequently, more bolls.

In summary, the transplanting method and integrated fertilizer application positively impacted boll number and yield by creating favorable conditions for plant growth, nutrient uptake, and reproductive development.

As indicated in Table 5, the chemical+organic treatment significantly enhanced boll weight, yielding increases of 49.2% and 58.1% over the control in 2020 and 2021, respectively, within the transplanting system. The direct seeding system also showed substantial improvements, with boll weights 64.1% and 64.5% higher than the control in the corresponding years. No significant difference in boll weight was observed between the two planting methods in the control treatment.

Boll weight is a critical determinant of cotton yield, primarily influenced by genetics but also shaped by environmental conditions. The rapid nutrient release from chemical fertilizers, coupled with the robust root system of transplanted cotton, likely contributed to increased photosynthesis and subsequent boll weight. Conversely, the gradual nutrient release from organic fertilizers in the direct seeding system coincided with boll growth, potentially leading to larger, fewer bolls. Previous research supports the notion that adequate nutrient availability during boll development is crucial for maximizing boll weight (Emara and Hamoda, 2023).

The combination of chemical and organic fertilizers fostered optimal plant growth conditions. This integrated approach mitigates the negative effects of chemical fertilizers while enhancing their efficiency. Furthermore, it improves soil health, leading to increased organic carbon content, biological activity, and overall soil quality, all of which positively impact plant growth and yield (Bai *et al*., 2022). Balanced nutrient supply, particularly during reproductive growth stages, is essential for maximizing both vegetative and reproductive development.

Seed and lint cotton yield

Nutrition systems and their interaction with planting method and year significantly influenced seed cotton yield. However, other factors did not impact this yield. Lint yield was primarily affected by year and the interaction of nutrition systems, planting method, and year.

The chemical+organic treatment consistently produced higher seed cotton yields than other treatments, regardless of planting method. Transplanting generally led to higher seed cotton yields compared to direct seeding, except in the control treatment. The chemical+organic treatment significantly increased seed cotton yield in both planting methods compared to other treatments, with more pronounced effects in transplanting.

Lint yield patterns mirrored those of seed cotton yield. The chemical+organic treatment combined with transplanting resulted in the highest lint yield. While chemical+organic and chemical fertilizer treatments produced similar lint yields in direct seeding, the chemical+organic treatment significantly outperformed others in the transplanting system.

Seed cotton yield was enhanced by 25% in both the transplanting and conventional planting systems when chemical and organic fertilizers were applied compared to the control treatment. This yield improvement is attributed to the optimized nutrient availability in integrated systems, aligning better with crop nutrient demands. While initial nitrogen levels might be lower in integrated systems, the sustained mineralization process ensures a prolonged nutrient supply during reproductive stages (Mooleki *et al.,* 2004). Enhanced microbial activity, improved soil structure, and increased water holding capacity due to organic matter incorporation contribute to better plant growth and yield (Shata *et al*., 2007; Du *et al.,* 2020).

Transplanting significantly increased seed cotton yield compared to direct seeding. This enhancement is attributed to the greater number and weight of bolls produced in the transplanting system. By initiating growth in seed trays, transplanting allows for an earlier start to the plant's life cycle, resulting in earlier flowering and squaring stages. In contrast, direct seeding often leads to delayed flowering and increased susceptibility to cold temperatures, impacting boll maturity and ultimately reducing yield. These findings align with previous research by Mehrabadi (2018) and Khajeh Mozaffari *et al*. (2019), who also reported higher yields and improved seed quality in transplanted cotton.

Fiber quality

Analysis of variance (ANOVA) revealed significant effects of nutrition systems and planting methods on fiber length and strength. Fiber uniformity was significantly influenced by the interaction between nutrition systems and planting methods, while fiber micronaire was only affected by planting method. Other tested parameters showed no significant differences (Table 4).

The chemical+organic treatment yielded the longest fiber length (36.3 mm), which was comparable to the organic treatment. This treatment resulted in a 17.5% increase in fiber length compared to the control. The shortest fibers were observed in the control group (Figure 2). The transplanting system produced 8.94% longer fibers than direct seeding over the two-year study period.

Table 5. The interaction effects of nutrient systems and planting method on boll number per plant, boll weight, seed cotton yield, Lint percentage and Lint yield.

Planting method	Nutrient systems	Boll number per plant		10-boll weight (g)		Seed cotton yield (Kg ha^{-1})		Lint yield (Kg ha^{-1})	
		2010	2011	2010	2011	2010	2011	2010	2011
Transplanting	Control	5.66±2.67 c	6.70±0.333 c	41.0±4.00 e	46.17±4.83 e	1437±95.5 b	2549±94.1 e	478±56.2 d	879±23.8 d
	Chemical	8.67±0.66 b	9.73±1.37 b	62.0±10.3 c	82.2±2.17 bc	2299±71.3 a	3554±54.9 ab	996±22.0 a	1171±34.5 c
	Organic	7.67±1.17 bc	7.43±1.26 c	53.9±5.65 d	70.4±2.03 c	1943±31.3 b	3067±90.6 d	516±104 d	1275±25.8 b
	Chemical+organic	11.7±0.67 a	12.93±0.23 a	80.7±5.89 b	110±4.20 a	2897±86.3 a	3579±23.3 ab	835±173 b	1470±12.9 a
Direct-seeding	Control	5.50±1.75 c	6.00±1.27 c	35.0±5.00 e	35.4±1.10	2176±25.3 ab	2682±76.4 e	764±54.5 c	912±47.6 d
	Chemical	9.25±0.50 b	9.00±2.23 b	64.0±5.62 c	72.1±2.40 c	2481±80.0 a	3436±18.2 b	769±111 c	1342±22.9 ab
	Organic	8.67±1.00 b	9.87±.35 b	51.0±1.47 d	62.0±1.70 d	2227±95.5 ab	3272±33.3 c	830±54.5 b	1220±22.4 b
	Chemical+organic	10.0±1.17 a	11.1±3.25 a	97.6±3.04 a	99.7±3.99 ab	2531±38.3 a	3733±17.2 a	840±19.3 b	1493±29.9 a

Similar letters within the same columns denote insignificant differences based on DMRT level of 5% (Mean±SD)

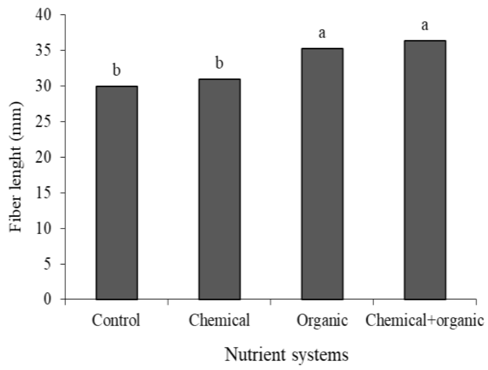

Fig. 2. Effect of nutrient systems on fiber length.

Fiber uniformity varied based on both planting method and treatment. In the chemical+organic and organic treatments, transplanting resulted in higher fiber uniformity compared to direct seeding. Conversely, in the control and chemical treatments, direct seeding produced more uniform fibers. While no significant difference in fiber uniformity was observed between the chemical+organic and organic treatments under the transplanting system, the organic treatment exhibited higher fiber uniformity than the chemical+organic treatment within the direct seeding system (Figure 3).

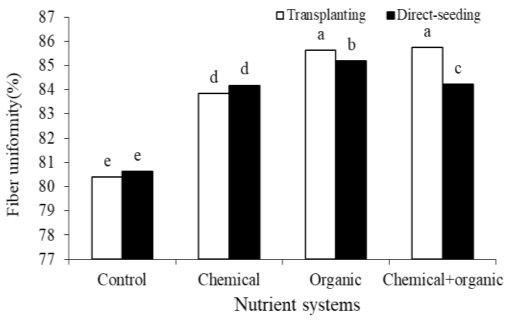

Fig. 3. Effect of nutrient systems and planting method on fiber uniformity.

Over the two-year study period, the combined chemical and organic treatment produced the highest fiber strength, although there was no significant difference compared to the treatments involving either chemical or organic fertilizers alone. The absence of fertilization resulted in a 22.5% reduction in fiber strength compared to the chemical and organic combination (Figure 4). Transplanting led to a 4.66% increase in fiber strength compared to direct seeding across both seasons. However, direct seeding resulted in coarser fibers with a higher micronaire value (4.88) compared to transplanting (4.34).

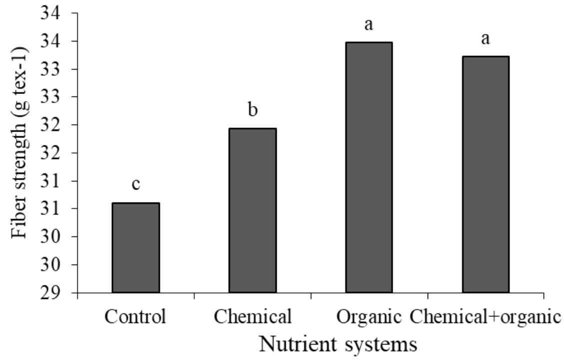

Fig. 4. Effect of nutrient systems on fiber strength.

While cotton fiber quality is primarily considered a genetic trait, environmental factors can significantly influence it. These factors include weather conditions during boll development, nutrient availability, planting date, plant density, irrigation, variety, solar radiation, soil properties, and atmospheric carbon dioxide concentration. Soil fertility positively correlates with fiber yield, and suboptimal fertility can reduce fiber quality. Nitrogen application studies have shown that maximum fiber length (30.6 mm) is achieved at 120 kg N/ha, with excessive nitrogen leading to shorter fibers due to increased vegetative growth and chlorophyll production. Consistent with our findings, optimal micronaire (3.5-4.9 µg/inch) and fiber length (25.4-28.6 mm) were observed at lower nitrogen levels (100 kg N/ha). The enhanced fiber strength in our transplanted cotton is attributed to favorable early growth conditions, leading to increased cellulose deposition and thicker fiber walls. These findings align with previous research indicating improved fiber strength in transplanted cotton compared to other planting methods.

Nitrogen Efficiency Indices

Agronomic nitrogen use efficiency (ANUE) was highest in the chemical treatment and direct seeding combination, significantly outperforming other treatments. While no significant difference in ANUE was observed between organic and chemical+organic treatments under direct seeding, the chemical and chemical+organic combinations exhibited similar ANUE values in the transplanting method, with the organic treatment demonstrating the lowest efficiency (Figure 5). The reduced ANUE in the organic treatment was primarily attributed to lower seed cotton yield compared to other treatments. Conversely, the higher ANUE in the chemical treatment was linked to its superior seed cotton yield. Genetic, environmental, and agronomic factors collectively influence yield and nitrogen use efficiency, with nitrogen fertilizer management emerging as a crucial agronomic factor impacting both seed yield and nitrogen efficiency (Balasubramanian *et al*., 2004).

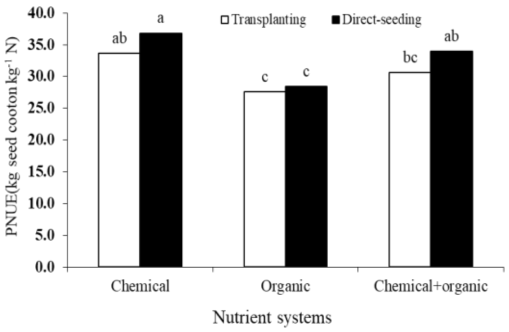

Fig. 5. Effect of nutrient systems and planting method on agronomic nitrogen use efficiency.

Nitrogen recovery efficiency (NRE) varied significantly between transplanting and direct seeding methods, with transplanting consistently exhibiting higher NRE across all nutrient regimes. The combination of transplanting and chemical fertilization yielded the highest NRE in this study. The reduced nitrogen uptake in direct seeding is attributed to lower leaf area compared to transplanted plants. Due to faster vegetative growth under higher temperatures, directly sown plants have less time for leaf development, impacting nitrogen absorption. Chemical**.**

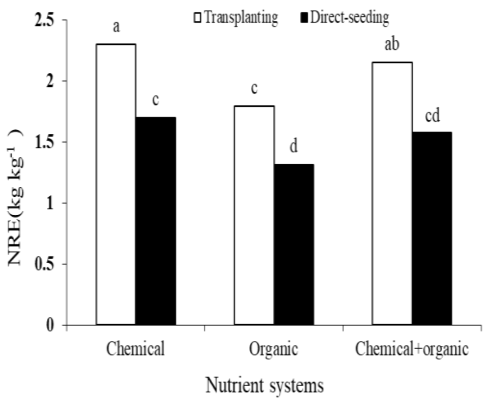

Fig. 6. Effect of nutrient systems and planting method on nitrogen recovery efficiency.

No significant differences in nitrogen use efficiency (NUE) were observed between the different nutrition systems in the transplanting method. However, the chemical fertilizer treatment exhibited higher NUE compared to organic or combined organic-chemical systems. In contrast, the direct cultivation method showed the highest NUE in the chemical fertilizer treatment, significantly outperforming other treatments. No significant difference in NUE was found between organic and combined organic-chemical systems under direct cultivation.

These varying responses in NUE between planting methods and nutrition systems can be attributed to differences in nitrogen absorption rates and crop yield. Factors such as nitrogen source type, application rate, timing, and method, along with soil organic matter, moisture, and weather conditions, can significantly influence nitrogen availability, uptake, and utilization by cotton plants.

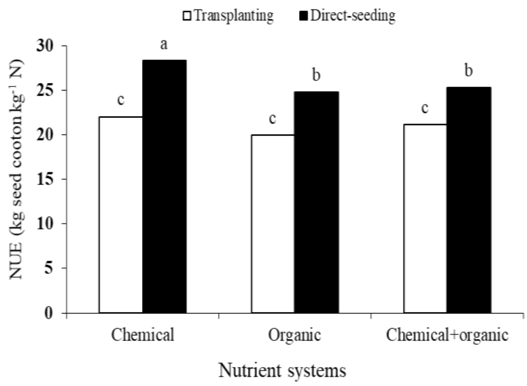

Fig. 7. Effect of nutrient systems and planting method on agronomic nitrogen use efficiency.

Conclusion

The results of this study demonstrate that an integrated fertilization approach, combining both chemical and organic fertilizers, surpasses the performance of solely chemical or organic fertilization methods in enhancing yield components, seed cotton yield, and fiber quality. Regardless of the planting system, whether direct seeding or transplanting, the 50% chemical and 50% organic fertilizer combination proved to be the most effective nutrient management strategy for maximizing cotton production and quality. Based on these findings, it is recommended to adopt the integrated fertilization method in conjunction with transplanting in the study region or under similar climatic conditions to optimize cotton yields and quality.

Consent for publication:

All authors declare their consent for publication.

Author contribution:

The manuscript was edited and revised by all authors.

Conflicts of Interest:

The author declares no conflict of interest.

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