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Mitigating salinity impact on cotton through precision nitrogen management

Sanjar Khozhiev[1*], *Barno* Davronov[2], *Feruza* Xamidova[3], *Dilfuza* Narzullaeva[1], *Azizjon* Qodirov[1], and *Gulshan* Xaitova[1]

[1]Bukhara State University, Bukhara, Uzbekistan
[2]Karshi State University, Karshi, Uzbekistan
[3]Bukhara State Medical Institute named after Abu Ali ibn Sino, Faculty of Biomedicine, Bukhara, Uzbekistan

Abstract. This study is part of a coordinated research program conducted on the same experimental plots, investigating the effects of nitrogen fertilization on cotton under varying salinity levels. Parallel studies focus on growth parameters, physiological traits, biomass accumulation, yield components, providing a comprehensive assessment of crop responses to nutrient management in saline environments. This study presents a large-scale field investigation of the interaction between soil salinity and precision nitrogen fertilization on key yield components of cotton (*Gossypium hirsutum L.*). Within the framework of precision agriculture and specific crop management, the study evaluates nutrient optimization under abiotic stress to improve reproductive development and resource use efficiency. Field experiments were conducted on irrigated meadow-alluvial soils classified into four salinity levels based on electrical conductivity. A randomized complete block design with nitrogen application rates ranging from 0 to 350 kg/ha allowed for detailed biometric assessment. Yield-related traits, including sympodial branches, buds, flowers, and bolls, were measured at three phenological stages. Analysis of variance results showed that increasing salinity significantly reduced all yield components, while precise nitrogen application mitigated these effects. The optimal nitrogen application rate was 250 kg/ha, maximizing yield components under non-saline conditions and maintaining productivity under high salinity. These results highlight the importance of data-driven variable-rate fertilizer application for increasing cotton yields in saline soils and contribute to decision support systems for sustainable production on marginal lands. The outcomes have practical implications for developing efficient fertilizer strategies and improving crop tolerance to salinity stress, particularly in arid and semi-arid zones.

1 Introduction

In this article, the complex interaction between salinity levels in soils and nitrogen fertilizer application on the yield elements of cotton (Gossypium hirsutum L.) is analyzed with the aim

[*] Corresponding author: hojiyevsanjar75samadov@gmail.com

of deepening our understanding of how these key factors impact cotton production under various agroecological conditions. The growing global concern regarding soil degradation—particularly salinization—and the increasing demand for cotton as a strategic agricultural crop in many regions necessitate a thorough examination of the physiological, morphological, and yield-related responses of cotton to these stressors. Soil salinity is a significant constraint to agricultural productivity, especially in arid and semi-arid regions where irrigation is essential but frequently contributes to salt accumulation in the soil profile.

Nitrogen is a major nutrient required in relatively large quantities for the synthesis of vital biomolecules, including amino acids, nucleic acids, and chlorophyll, which collectively support the structural and metabolic integrity of the plant [1-3].

However, under saline conditions, nitrogen availability and utilization efficiency decline due to factors such as ion competition, altered root membrane permeability, and microbial inhibition in the rhizosphere. Therefore, optimizing nitrogen fertilization in saline soils becomes a delicate but essential strategy to mitigate salinity stress and sustain cotton productivity. The balance between applying sufficient nitrogen to support yield formation and avoiding excess fertilization that may exacerbate salt stress or environmental harm is particularly critical. Numerous studies have shown that nitrogen application can partially compensate for salinity-induced growth inhibition, especially when applied in regulated doses and in forms that improve nitrogen use efficiency (NUE). Furthermore, nitrogen enhances the photosynthetic capacity of the plant, promotes better root development, and strengthens the source-sink relationship, which is crucial for boll setting and retention [4-6].

The degree of salinity, often quantified through electrical conductivity (EC) of the soil extract, is a determining factor in the extent of damage or adaptation observed in cotton. Low to moderate levels of salinity may cause sub-lethal stress that triggers adaptive responses in cotton, such as osmolyte accumulation and selective ion transport, while higher salinity levels often result in a breakdown of cellular homeostasis and tissue necrosis. These physiological disruptions directly correlate with yield losses, making the management of salinity crucial for sustainable cotton farming. Moreover, salinity stress is dynamic; its severity may vary over time depending on irrigation practices, rainfall patterns, groundwater levels, and soil texture—all of which interact with nitrogen dynamics in the soil-plant system [7,8].

From an agronomic standpoint, it is crucial to examine how different nitrogen fertilizer rates and application methods can mitigate the adverse effects of salinity on yield attributes. These include plant height, the number of sympodial and monopodial branches, leaf area index, the number and weight of bolls per plant, and ultimately seed cotton yield and fiber quality traits such as staple length, micronaire value, and tensile strength. A comprehensive understanding of the influence of salinity and nitrogen interactions on these yield components is necessary to develop location-specific, resource-efficient, and environmentally sound management practices.

Advancements in agricultural research have also shown that not all nitrogen sources are equally effective under saline conditions. The use of urea, ammonium nitrate, calcium ammonium nitrate, and slow-release fertilizers each presents different responses in terms of nitrogen availability, leaching losses, and compatibility with the salt-affected environment. In addition, split applications of nitrogen, as opposed to single-dose fertilization, have shown promise in improving nitrogen uptake and reducing the negative impact of salinity during sensitive phenological stages. Emerging technologies such as fertigation, use of nitrogen inhibitors, and biofertilizers also offer alternative avenues to optimize nitrogen utilization under salinity stress [9-10].

In many cotton-producing countries, especially in Central Asia, India, Pakistan, Egypt, and parts of the southern United States, the challenge of increasing cotton yields on salinized lands is intertwined with socio-economic constraints, water scarcity, and climate change pressures. The indiscriminate use of nitrogen fertilizers not only leads to economic inefficiency but also contributes to environmental degradation through nitrate leaching, greenhouse gas emissions (particularly nitrous oxide), and eutrophication of water bodies. Thus, a sustainable approach to cotton cultivation on saline soils requires precise nitrogen management aligned with soil testing, weather forecasting, and real-time plant diagnostics.

This study aims to fill knowledge gaps in understanding how varying degrees of soil salinity interact with different nitrogen fertilizer regimes to influence the physiological performance and yield elements of cotton. It seeks to quantify the effects of salinity and nitrogen on key parameters such as boll number and weight, seed cotton yield, harvest index, and fiber quality traits.

2 Materials and methods

The experimental study was carried out on irrigated meadow-alluvial soils characterized by distinct salinity classes: non-saline, slightly saline, moderately saline, and strongly saline soils. The primary objective was to determine how the interaction between soil salinity and nitrogen fertilizer levels influences key yield components such as the number of sympodial branches, buds, flowers, and bolls during the growth and development phases of cotton.

The soil types used in the experimental plots were classified according to the electrical conductivity (EC) of their saturation extract as follows:

Non-saline soils: EC < 2 dS/m
Slightly saline soils: EC = 2–4 dS/m
Moderately saline soils: EC = 4–8 dS/m
Strongly saline soils: EC > 8 dS/m

The study employed a randomized complete block design with eight treatment variants replicated in all four salinity categories. Each treatment involved the application of different nitrogen fertilizer rates, supplemented with a uniform background application of phosphorus and potassium at a rate of P175K125 kg/ha. Nitrogen was applied in the form of ammonium nitrate in the following rates per hectare:

Control (no fertilizer)
Background P175K125 (Base only)
Base + N100
Base + N150
Base + N200
Base + N250
Base + N300
Base + N350

Nitrogen fertilizer was applied in three equal split doses at specific crop development stages: at planting, at the beginning of flowering, and during boll formation. All agronomic practices such as irrigation, weeding, and pest control were performed uniformly across all experimental plots.

The observations were recorded at three key phenological stages of cotton development:

1.07 (early vegetative stage)
1.08 (flowering stage)
1.09 (boll formation and ripening stage)

At each of these time points, the following biometric and yield-related parameters were recorded on five representative plants per replication:

Number of sympodial branches per plant
Number of buds per plant
Number of flowers per plant
Number of bolls per plant

Data were collected on-site in field conditions using standard botanical and agronomic techniques.

3 Results and discussion

Cotton yield is determined by its growth, development and physiological response to environmental factors. Yield components are closely related to the number of cotton bolls, seed size and weight, fibre length and quality, the plant's ability to absorb nutrients and its resistance to stress conditions. Soil salinity and nitrogen fertilisers have a direct impact on these yield components and play a key role in the quantitative and qualitative formation of the cotton crop.

As soil salinity increases, cotton yields decline. High levels of sodium, chlorine and other soluble salts in saline soils limit the absorption of water and minerals through the root system. As a result, the vegetative organs of the plant — leaves and buds — are not sufficiently nourished, the number of buds decreases, and seed weight and fibre length decrease. Salinisation also significantly reduces the quality of the harvest: fibres become shorter, strength decreases, and elasticity and fibre separation decrease. At the same time, salt stress reduces plant metabolism, slows down the process of photosynthesis and reduces the formation of assimilates, which negatively affects yield components.

Nitrogen fertilisers have a positive effect on cotton yield components. Nitrogen accelerates vegetative growth processes, increases leaf surface area and enhances photosynthesis intensity. As a result, the number of buds increases, seed development accelerates and seed weight increases. At the same time, nitrogen improves fibre length, quality and density. Optimal nitrogen nutrition maximises yield factors by providing sufficient assimilates during plant growth and fruiting.

The interaction between salinity and nitrogen fertilisers has a complex and multifactorial effect on cotton yield. Under conditions of low salinity, optimal nitrogen fertilisation significantly increases cotton yield components, increases the number of buds and seed weight, and improves fibre length and quality. However, under conditions of moderate to severe salinity, the positive effect of nitrogen may be limited. In saline soils, due to insufficient absorption of water and minerals through the root system, nitrogen fertilisation cannot fully improve fertility. Therefore, when growing cotton in saline conditions, along with the use of nitrogen fertilisers, it is important to carry out soil reclamation, optimise the irrigation system and implement other agrotechnical measures.

When studying the number of sympodial branches and yield elements of cotton grown on soils with different degree of salinity, the best indicators were observed on non-saline soils and partially on slightly saline soils. For example, on non-saline soils the number of sympodial branches of cotton in the control variant without fertilizer application was 1.07; 1.08; 1.09 1.2; 6.5; 8.8 pieces, which was 1.6; 8.1;10.0 pieces, these indicators were higher in variants with application of all nitrogen fertilizers. For example, when background + N100 kg was applied at 3 specific dates i.e. 1.07; 1.08; 1.09 1.9; 9.2; 13.1 pieces, the rest of the variants also showed an increase in the indices from 2.3 to 2.9 pieces when counted at 1.07, 10.5 to 12.0 pieces when counted at 1.08 and 14.4 to 16.2 pieces when counted at 1.09 (Tables 1-2).

The number of sympodial branches on slightly saline soils in all variants of experiment at determination on 1.07 the number varied from 1.0 to 2.6 pieces, on moderately saline soils from 0.8 to 2.4 pieces, at determination of these indicators on 1.08 the number varied from 5.8 to 11 pieces on slightly saline soils, on moderately saline soils from 5.0 to 10.0 pieces, and on strongly saline soils from 4.5 to 9.5 pieces. When determining the term of determination at the end of vegetation, i.e. 1.09 the number of sympodial branches on slightly saline soils was from 7.2 to 15.0 pieces, on medium saline soils from 6.3 to 13.1 pieces, on strongly saline soils from 5.5 to 12.6 pieces.

Table 1. Effect of different rates of nitrogen fertilizers and different saline irrigated meadow-alluvial soils on the number of sympodial branches and yield elements of cotton, on the example of one plant

№	Variants	Sympodial branches, pcs.			Fruit elements, pcs.			
					Bud	Flower	Box	
		1.07	1.08	1.09	1.07	1.08	1.08	1.09
Non-saline								
1	Control	1.2 ± 0.02	6.5 ± 0.8	8.8 ± 0.12	5.2 ± 0.29	2.0 ± 0.2	2.5 ± 1.083	5.7 ± 1.038
2	P175K125-Base	1.6 ± 0.03	8.1 ± 1.01	10.0 ± 0.17	6.0 ± 0.40	3.1 ± 1.08	4.4 ± 1.097	7.5 ± 1.03
3	Base+N100	1.9 ± 0.01	9.2 ± 1.02	13.1 ± 0.6	8.2 ± 0.33	4.5 ± 1.065	4.5 ± 0.16	10.2 ± 1.091
4	Base+N150	2.3 ± 0.3	10.5 ± 0.2	14.4 ± 1.0	8.9 ± 0.12	5.9 ± 1.032	4.3 ± 0.23	12.5 ± 1.042
5	Base+N200	2.5 ± 0.24	10.9 ± 1.0	14.9 ± 1.09	10.2 ± 0.6	6.4 ± 1.065	5.2 ± 0.214	13.0 ± 1.09
6	Base+N250	2.7 ± 0.17	11.6 ± 1.0	15.4 ± 1.01	11.2 ± 0.9	7.5 ± 1.009	5.9 ± 0.62	13.8 ± 0.25
7	Base+N300	2.8 ± 0.12	11.9 ± 1.0	15.1 ± 0.04	12.0 ± 0.7	8.3 ± 1.005	6.0 ± 0.346	14.0 ± 1.07
8	Base+N350	2.9 ± 0.10	12.0 ± 1.03	16.2 ± 0.45	12.4 ± 1.06	8.4 ± 1.05	7.2 ± 1.036	14.7 ± 1.1
Weakly saline								
1	Control	1.0 ± 0.06	5.8 ± 0.29	7.2 ± 1.09	4.5 ± 1.065	1.5 ± 0.025	2.0 ± 0.6	5.0 ± 1.06
2	P175K125-Base	1.4 ± 0.01	7.4 ± 1.06	9.2 ± 1.05	5.2 ± 1.048	2.8 ± 0.036	3.8 ± 0.8	7.0 ± 1.07
3	Base+N100	1.7 ± 0.15	8.3 ± 1.05	11.4 ± 0.5	7.3 ± 1.037	3.6 ± 0.46	3.9 ± 0.12	9.3 ± 1.02
4	Base+N150	2.0 ± 0.3	9.4 ± 1.05	12.3 ± 0.1	7.6 ± 1.048	4.8 ± 1.064	4.0 ± 0.10	11.2 ± 1.010
5	Base+N200	2.2 ± 0.5	9.8 ± 1.09	12.7 ± 1.0	9.3 ± 1.036	5.6 ± 1.024	4.6 ± 0.5	11.9 ± 1.006
6	Base+N250	2.5 ± 0.12	10.2 ± 1.0	14.0 ± 1.0	10.0 ± 1.05	6.4 ± 1.097	5.0 ± 0.8	12.7 ± 1.049
7	Base+N300	2.4 ± 0.10	10.5 ± 1.0	14.4 ± 0.3	11.2 ± 1.01	7.4 ± 1.078	5.5 ± 0.14	13.0 ± 1.064
8	Base+N350	2.6 ± 0.17	11.0 ± 1.0	15.0 ± 0.1	11.5 ± 1.06	7.8 ± 1.003	6.4 ± 0.31	13.5 ± 1.036

Although nitrogen fertilizer rates had a positive effect on the number of cotton sympodial branches, the number of sympodial branches decreased with increasing degree of salinity. Although this was noticeable on slightly saline soils, it was clearly manifested on medium and highly saline soils.

The amount of cotton fruit elements is one of the main indicators determining its yield. If the plant during growth and development is exposed to unfavorable weather conditions, soil salinity, dry winds, various diseases, it begins to lose elements of yield, these include salinization. In salinization the amount of fruit elements is low, as a result on saline soils the yield was low.

When determining the number of cotton buds on saline soils on 1.07 the number of buds in the control variant without fertilizer application was 5.2 pieces, and on P175 K125 background - 100; 150; 200; 250; 300; At fertilizer rate of 350 kg in the sequence of fertilizer application 8.2; 8.9; 10.2; 11.2; 12.0; 12.4 pieces. The number of buds on slightly saline soils in all studied 8 variants ranged from 4.5 to 11.5 pieces, on medium saline soils from 4.0 to 10.8 pieces, on strongly saline soils from 3.5 to 9.6 pieces.

When determining the number of flowers in cotton plants on 1.08 the number of non-saline soils in the control variant was 2.0 pieces, and in all variants with the use of fertilizers is sharply higher. For example, in the background variant with phosphorus and potassium fertilizers it was 3.1 pieces, in the variant with background + N-100 kg - 4.5 pieces, in the variant with background + N-150 kg - 5.9 pieces, and in the other variants with nitrogen fertilizers it varied from 6.4 to 8.4 pieces.

Table 2. Effect of different rates of nitrogen fertilizers and different saline irrigated meadow-alluvial soils on the number of sympodial branches and yield elements of cotton, on the example of one plant

№	Variants	Sympodial branches, pcs.			Fruit elements, pcs.			
					Bud	Flower	Box	
		1.07	1.08	1.09	1.07	1.08	1.08	1.09
Moderately saline								
1	Control	0.8 ± 0.009	5.0 ± 0.29	6.30 ± 0.34	4.0 ± 0.032	1.3 ± 1.02	1.5 ± 0.14	4.5 ± 0.05
2	P175K125-Base	1.2 ± 0.01	6.5 ± 0.40	8.5 ± 0.025	5.5 ± 1.025	2.0 ± 1.04	3.0 ± 0.2	6.5 ± 0.24
3	Base+N100	1.5 ± 0.06	7.4 ± 1.09	10.6 ± 0.06	6.6 ± 1.032	3.2 ± 1.07	3.1 ± 0.4	9.0 ± 0.71
4	Base+N150	1.7 ± 0.014	8.3 ± 0.33	11.2 ± 0.01	6.9 ± 1.003	4.0 ± 1.01	3.5 ± 0.7	10.5 ± 0.31
5	Base+N200	2.0 ± 0.2	8.5 ± 0.65	11.0 ± 0.01	8.2 ± 1.006	4.5 ± 0.01	4.0 ± 1.07	11.0 ± 1.06
6	Base+N250	2.3 ± 0.3	9.7 ± 1.098	12.8 ± 0.07	9.5 ± 1.054	5.5 ± 0.25	4.5 ± 1.06	12.0 ± 0.12
7	Base+N300	2.0 ± 0.6	9.0 ± 1.045	12.5 ± 0.02	10.1 ± 1.03	6.8 ± 0.64	5.0 ± 1.03	12.5 ± 0.21
·	Base+N350	2.4 ± 0.24	10.0 ± 1.05	13.1 ± 0.09	10.8 ± 1.09	7.0 ± 0.32	6.0 ± 1.09	13.0 ± 0.14
Strongly saline								
1	Control	0.5 ± 0.02	4.5 ± 0.14	5.5 ± 1.01	3.5 ± 0.024	1.2 ± 0.008	1.2 ± 0.07	4.0 ± 1.07
2	P175K125-Base	1.0 ± 1.02	5.3 ± 0.2	8.0 ± 0.03	5.0 ± 0.065	2.2 ± 1.02	2.5 ± 0.75	6.0 ± 1.002
3	Base+N100	1.2 ± 0.35	7.0 ± 0.5	10.0 ± 0.04	6.0 ± 1.002	3.0 ± 0.23	3.0 ± 0.34	8.0 ± 1.009
4	Base+N150	1.5 ± 0.10	8.0 ± 0.6	10.5 ± 0.01	6.2 ± 1.005	3.5 ± 0.24	3.0 ± 0.1	8.4 ± 0.32
5	Base+N200	1.8 ± 0.32	8.2 ± 0.014	10.6 ± 1.05	7.5 ± 1.005	4.0 ± 0.52	3.5 ± 0.18	9.5 ± 0.15
6	Base+N250	1.7 ± 1.025	9.2 ± 0.23	11.5 ± 1.08	9.0 ± 1.06	5.0 ± 0.36	4.0 ± 0.71	10.5 ± 1.02
7	Base+N300	2.0 ± 1.06	8.5 ± 0.5	11.2 ± 0.06	9.5 ± 0.025	6.0 ± 1.006	4.5 ± 0.13	11.2 ± 1.00
8	Base+N350	2.2 ± 1.032	9.5 ± 0.1	12.6 ± 0.01	9.6 ± 1.067	6.5 ± 1.025	5.2 ± 0.33	12.0 ± 1.07

The number of flowers on slightly saline soils was slightly less than on non-saline soils when we determined them on 1.08 date, in the control variant it was 1.5 pieces, in the background variant - 2.8 pieces, these indicators in all variants with application of nitrogen fertilizers were from 3.6 to 7.8 pieces. When determining these indicators on medium saline soils in the above terms in all variants of the experiment were observed from 1.3 to 7.0 pieces, and on highly saline soils from 1.2 to 6.0 pieces.

The number of flowers on cotton contributes to the number of bolls formed. The number of bolls formed by cotton can be used to estimate its yield. When counting the number of bolls at 1.08 and the end of vegetation, i.e. at 1.09 in non-saline soils in the experimental variants when determined at 1.08 the number of bolls varied from 2.5 to 7.2 pieces, in studies conducted on slightly saline soils from 2 to 7.2 pieces, and on medium saline soils from 1.2 to 5.2 pieces, this indicator when counted at 1. 09 the number of boxes varied from 5.7 to 14.7 pieces on non-saline soils, from 5.0 to 13.5 pieces on slightly saline soils, from 4.5 to 13.0 pieces on medium saline soils, and from 4.0 to 12.0 pieces on highly saline soils.

4 Conclusion

In conclusion as soil salinity increases, the growth rate of cotton plants and the accumulation of crop elements slow down, and this is particularly evident in moderately and highly saline soils. The application of nitrogen fertilizers on soils with varying degrees of salinity has a positive effect on the growth and development of cotton, the accumulation of crop elements, and when nitrogen fertilizers are applied at a rate of 250 kg/ha, the most optimal conditions for growth, development, and crop accumulation are created.

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