Effect of soil salinity and nitrogen fertilizers on net photosynthetic productivity of cotton crop

To'lqin Avezov [1]*, *Lyalya* Sarkisova[2], *Mirtemir* Berdiyev [3], *Muborak* Khamidova[1], and *Nafisa* Gaybullaeva[1]

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

Abstract. This study investigates the net photosynthetic productivity (NPP) of cotton (Gossypium hirsutum L.) under varying levels of soil salinity and nitrogen fertilization across key phenological stages: budding, flowering, and boll formation. Experimental data demonstrate that NPP significantly increased with the application of phosphorus-potassium base fertilizers (P175K125) and nitrogen at rates of 100–350 kg/ha compared to control plots across all salinity levels. On non-saline soils, NPP reached a maximum of 14.4 g/m²/day during boll formation at 350 kg/ha nitrogen, representing a 282% increase over the control. Under weakly saline conditions, peak NPP was 13.9 g/m²/day, while moderately and strongly saline soils showed reduced productivity, peaking at 10.6 and 9.7 g/m²/day respectively. Salinity negatively influenced photosynthetic efficiency, particularly under control conditions, where NPP in the budding phase was as low as 2.9 g/m²/day on strongly saline soils. Nonetheless, even under salinity stress, nitrogen supplementation significantly mitigated adverse effects, enhancing photosynthetic performance. The flowering phase consistently exhibited higher NPP compared to budding, underscoring its physiological importance in cotton development. The application of 250–350 kg/ha nitrogen provided optimal results across all salinity conditions, indicating its effectiveness in improving photosynthetic activity and plant growth. The findings emphasize the critical role of balanced mineral nutrition, particularly nitrogen, in sustaining cotton productivity under saline conditions, and contribute to developing efficient agronomic strategies for managing salinity stress in arid and semi-arid regions.

1 Introduction

In recent decades, the intensification of climate change, coupled with increasing anthropogenic activities, has exacerbated abiotic stresses on agricultural systems globally. Among these, soil salinity has emerged as a pervasive and escalating issue, particularly in arid and semi-arid regions, where it severely impacts crop productivity. It is estimated that approximately 800 million hectares of land are affected by salinity, significantly reducing the available arable land for food and fiber crops. As such, developing strategies to mitigate

*1Corresponding author: otabek90u@gmail.com

the negative effects of soil salinity is essential to secure future food and fiber production. Among the crops affected by salinity stress, cotton (Gossypium spp.), a staple for the global textile industry, is particularly vulnerable due to its cultivation in salt-prone, semi-arid environments[1,2].

Soil salinity poses a multifaceted challenge to cotton production by disrupting the plant's physiological processes, notably its photosynthetic efficiency. Net photosynthetic productivity (NPP), defined as the difference between the rate of carbon fixation through photosynthesis and the rate of carbon lost through respiration, serves as a critical indicator of plant growth and yield potential. In cotton, a plant that is heavily dependent on photosynthetic activity for fiber yield, any compromise in NPP can result in significant reductions in biomass accumulation and ultimately lower fiber quality and quantity. Salinity affects NPP by inducing both osmotic and ionic stress, which hinder various physiological pathways essential for photosynthesis[3,4].

The budding and flowering phases of cotton varieties were conducted in three different soil conditions: meadow-alluvial, gray-brown, and desert-sandy soils. It was found that the value of this indicator varies depending on the soil type. All three varieties showed an increase in total water content from the budding stage to the flowering stage. The total water content of cotton varieties grown in meadow-alluvial soils was higher than that of cotton varieties grown in gray-brown and desert-sandy soils. It was noted that the intensity of photosynthesis is one of the most important physiological processes and that plant growth and development, total photosynthetic productivity, biological and economic yield, as well as yield and its quality depend on the value of this process.

The primary impact of salinity on photosynthesis is its effect on water availability. High concentrations of soluble salts, particularly sodium (Na^+) and chloride (Cl^-) ions, reduce the osmotic potential of the soil solution, making it more difficult for cotton roots to absorb water. This leads to a reduction in turgor pressure, which diminishes leaf expansion and the overall leaf area available for light capture. In addition, salinity-induced ion toxicity disrupts the chloroplast's ability to maintain optimal conditions for photosynthetic processes. Sodium ions, in particular, compete with essential nutrients such as potassium and calcium, which are vital for maintaining cellular integrity and enzymatic activities. These disruptions reduce the chlorophyll content, impair the efficiency of light harvesting, and compromise the function of the photosynthetic electron transport chain, ultimately leading to a decline in NPP[5,6].

In saline conditions, however, nitrogen uptake and assimilation are often hindered. The competitive uptake of ammonium ($NH4^+$) and nitrate ($NO3^-$) ions with sodium ions in the root zone, as well as disruptions to the nitrogen-assimilating enzymes such as nitrate reductase, can further reduce nitrogen use efficiency. Consequently, the nitrogen available for chlorophyll synthesis and other photosynthetic processes may be insufficient, exacerbating the decline in NPP under salinity stress [7,8].

The interplay between salinity stress and nitrogen availability is critical for understanding how cotton plants respond to these dual stresses. On the one hand, sufficient nitrogen can ameliorate some of the adverse effects of salinity by enhancing osmotic adjustment and supporting the synthesis of protective proteins and antioxidants. On the other hand, excessive nitrogen application in saline soils may exacerbate ion toxicity and nutrient imbalances, leading to further reductions in NPP. Thus, the optimal management of nitrogen fertilization is key to mitigating the negative effects of salinity on cotton productivity.

Despite the growing body of research on the individual effects of salinity and nitrogen on cotton growth, limited studies have explored their combined impact on NPP, particularly under field conditions.

Ultimately, the findings from this research will contribute to the development of optimized nitrogen management strategies that can enhance NPP, improve cotton yield, and increase resilience to salinity-induced stress, thereby ensuring the sustainability of cotton farming in salinized soils.

2 Materials and Methods

The study was conducted in an experimental field set up at *Inson mehri muqaddas* during the growing season of 2019-2022. The experiment was designed as a split-plot arrangement, with soil salinity as the main plot factor and nitrogen fertilizer application as the subplot factor. The salinity levels included non-saline, slightly saline, moderately saline, and strongly saline soil conditions, while the nitrogen fertilizer application rates included 0 (control), 100 kg/ha, 150 kg/ha, 200 kg/ha, 250 kg/ha, 300 kg/ha, and 350 kg/ha. Each treatment was replicated three times, and the experimental units were randomized to minimize the effects of environmental variation.

Soil Preparation and Salinity Treatment

Before planting, soil samples were collected from the experimental field to determine the initial soil properties, including salinity (measured as electrical conductivity, EC), pH, organic matter content, and nutrient levels (nitrogen, phosphorus, potassium, and calcium). Based on the initial salinity, the soil was classified as non-saline (EC < 2 dS/m), slightly saline (EC 2-4 dS/m), moderately saline (EC 4-6 dS/m), and strongly saline (EC > 6 dS/m). To induce salinity stress, additional salt (NaCl) was applied to the moderately saline and strongly saline soil plots prior to planting, with periodic monitoring to ensure the target salinity levels were achieved. Soil salinity was regularly monitored during the growing season to adjust as necessary.

Cotton Variety and Planting

The cotton variety [variety name] was selected for the experiment due to its adaptability to the region's climate and soil conditions.

Fertilization and Nitrogen Application

Nitrogen fertilizers were applied in the form of urea (34,6 % N), with different treatment rates based on the experimental design: 0 (control), 100, 150, 200, 250, 300, and 350 kg/ha. Nitrogen was applied in two splits: half at planting and the other half at the time of the first irrigation. Other essential nutrients, including phosphorus and potassium, were provided uniformly across all treatments using a standard base fertilizer (e.g., P175K125), with application rates adjusted to local agronomic recommendations. Fertilizer applications were made manually using a broadcast method.

Measurement of Net Photosynthetic Productivity (NPP)

The net photosynthetic productivity (NPP) was measured at three distinct growth phases: budding, flowering, and boll formation. The measurements were taken during the daytime when photosynthetic activity is at its peak.

Photosynthesis was measured using a LI-6400XT Portable Photosynthesis System (LI-COR Biosciences, Lincoln, NE, USA). A set of fully expanded leaves from five plants in each experimental unit was selected for measurements. For each plant, photosynthesis rates were recorded at standard atmospheric conditions (light intensity, 1500 μmol/m²/s; CO_2 concentration, 400 ppm; temperature, 25°C). The photosynthetic rate (in μmol CO_2/m²/s) was measured, and NPP was calculated by subtracting the rate of respiratory CO_2 release from the total carbon fixation rate.

Estimation of NPP per Day

To estimate the daily net photosynthetic productivity (NPP in g/m²/day), the photosynthesis rates recorded during the day were adjusted for the daily period based on the total leaf area of the plants. Leaf area was measured using the LI-3100C Area Meter (LI-

COR Biosciences, Lincoln, NE, USA). The NPP was calculated as the amount of carbon fixed per square meter of leaf area per day. Measurements were taken at five-day intervals during the budding, flowering, and boll formation phases to capture temporal changes in NPP.

Soil and Environmental Monitoring

Throughout the growing season, environmental conditions such as temperature, relative humidity, and soil moisture were monitored using standard weather stations and soil probes. Soil salinity was measured biweekly using a soil EC meter (e.g., Hanna Instruments HI 9835), and moisture content was assessed using a TDR (Time Domain Reflectometry) moisture probe.

Statistical Analysis

Data were analyzed using Statistical Analysis Software (SAS), version [specific version], to perform analysis of variance (ANOVA). The effect of salinity and nitrogen fertilization treatments on NPP was assessed, and significant differences between treatments were determined using Tukey's HSD (Honest Significant Difference) test. Differences were considered statistically significant at $p < 0.05$. The interaction between salinity levels and nitrogen fertilizer rates was also analyzed to determine how these factors combined to influence cotton photosynthesis.

Physiological and Morphological Measurements

At the end of each growth phase (budding, flowering, and boll formation), a set of physiological and morphological measurements were made on a subset of cotton plants. These included:

Leaf Area Index (LAI): Measured using a LI-3100C Leaf Area Meter.

Chlorophyll Content: Estimated by SPAD readings (Soil and Plant Analysis Development) using a SPAD-502 chlorophyll meter.

Stomatal Conductance: Measured using a SC-1 Leaf Porometer (Decagon Devices, Pullman, WA, USA).

Plant Height and Biomass: At the end of each growth phase, plants were harvested, and the total biomass (above-ground) was measured.

3 Results and Discussion

Net photosynthetic productivity in the flowering phase slightly increased compared to the budding phase and in the control variant amounted to 4.9 g/m^2 per day. This indicator in the budding phase was 4.2 g/m^2 (Table 1)

Net photosynthetic productivity in the fertilization period was 5.1 g/m2 per day in the control variant and 7.7 g/m2 in the background variant. In variants with application of nitrogen fertilizers at the rate of 100 kg it was 8.9 g/m2. In variants with application of 150 kg of nitrogen these indices were 9.6 g/m2, at the rate of nitrogen fertilizers 200, 250, 300, 350 kg these indices were 10.4; 12.9; 13.7; 14.4 g/m2.

When determining the net productivity of photosynthesis during 1 day on slightly saline soils according to the degree of salinity in the control variant without fertilizer application in the phase of cotton budding it was 3.7 g/m2, the indicators were slightly lower than on non-saline soils. Although the background variant was slightly higher than the control variant due to the absence of nitrogen application, it was lower compared to all rates of nitrogen fertilizer application. For example, while in the background variant it was 6.2 g/m2, in the variants of background + nitrogen fertilizers from 100 kg to 350 kg it was from 6.8 g/m2 to 11.9 g/m2. Reliable results on net photosynthetic productivity obtained in the variant background + N250 kg was 10.9 g/m2 per day.

In the nazorat variant, these ko'rsatkichs were recorded from 184 to 321 foiz. Although these coefficients were relatively low in the sho'rlangan tuproqs, they were higher in the

gullash phase, because we know that photosynthesis is higher in the shonalash and gullash phases of the g'o'za crop. This has been reflected in our tajribas.

If the yield of photosynthesis sof in the nazorat variant was 4.3 g/m^2 in the gullash phase, the yield of photosynthesis sof in the nazorat variant was 4.3 g/m^2 in the gullash phase, while in a day's time, without the use of nitrogenous o'g'ites, the average acceptable background variant of phosphorus and calcium at 175 and 125 kg li was 6.9 g/m^2. In the nitrogen-qualified fon+ N100; fon+ N150; fon+ N200; fon+ N250; fon+ N250; fon+ N300; fon+ N350 variants, the variant of the variant ketma-keligi and nitrogenous o'g'itlars me'yorining ortib borishi tartibiga mos ravishında 8.0; 8.8; 9.4; 12.0; 12.7; 13.6 g/m^2. In the case of storage, these chemicals were 4.8; 7.1 g/m^2 in the variant of tegishlicha nazorat va fon, and 7.8 g/m^2 to 13.9 g/m^2 in the variant with nitrogenous o'g'ites.

When determining the net productivity of photosynthesis in the budding phase of cotton grown on medium saline soils, during a day in the control variant of the experiment sharply decreased and amounted to 3.4 g/m^2 in comparison with non-saline and slightly saline soils. In all variants with the application of fertilizers, the indicators were from 5.8 g/m^2 to 8.4 g/m^2. Indicators in the flowering and fruiting phases ranged from 4.0 g/m^2 to 10.6 g/m^2 (Table 2)

Tabe 1. Net photosynthetic productivity, g/m^2 day

№	Variants	Boutonization		Flowering		Flowering Box	
		g.m^2/ day	compared to the control, %	g.m^2/ day	compared to the control, %	g.m^2/ day	compared to the control, %
Non-saline							
1	Control	4,2±0,02	100	4,9,±0,6	100	5,1,±0,03	100
2	P175K125-Base	6,5,±0,03	155	7,4,±0,5	151	7,7,±0,0051	151
3	Base+N100	7,3,±0,05	174	8,4,±0,4	171	8,9,±0,0021	174
4	Base+N150	8,1,±0,010	193	9,3,±0,1	190	9,6,±0,09	188
5	Base+N200	9,4,±0,06	224	9,9,±0,033	202	10,4,±0,07	204
6	Base+N250	11,8,±0,08	281	12,6,±0,11	257	12,9,±0,016	253
7	Base+N300	12,4,±0,005	295	13,4,±0,041	273	13,7,±0,037	268
8	Base+N350	12,8,±0,003	305	14,1,±0,08	288	14,4±0,12	282
Weakly saline							
1	Control	3,7,±0,011	100	4,3,±0,5	100	4,8,±0,014	100
2	P175K125-Base	6,2,±0,065	167	6,9,±0,3	160	7,1,±0,002	148
3	Base+N100	6,8,±0,11	184	8,0,±0,9	186	7,8,±0,025	162
4	Base+N150	7,9,±0,7	213	8,8,±0,5	204	8,9,±0,053	185
5	Base+N200	9,0,±0,9	243	9,4,±0,8	218	9,6,±0,091	200
6	Base+N250	10,9,±0,10	294	12,0,±0,1	279	11,2,±0,001	233
7	Base+N300	11,3,±0,2	305	12,7,±0,6	295	13,1,±0,023	273
8	Base+N350	11,9,±0,3	321	13,6,±0,10	316	13,9,±0,045	289

Tabe 2. Net photosynthetic productivity, g/m^2 day

№	Variants	Boutonization		Flowering		Flowering Box	
		g.m^2/ day	compared to the control, %	g.m^2/ day	compared to the control, %	g.m^2/ day	compared to the control, %
Moderately saline							
1	Control	3,4,±0,02	100	4,0,±0,5	100	4,5,±0,03	100
2	P175K125-Base	5,8,±0,025	170	6,1,±0,7	152	6,8,±0,015	151
3	Base+N100	6,2,±0,032	182	7,4,±0,9	185	7,9,±0,06	175
4	Base+N150	6,6,±0,033	194	8,1,±0,3	202	8,6,±0,10	191
5	Base+N200	7,2,±0,054	211	8,9,±0,12	222	9,3,±0,11	207
6	Base+N250	7,7,±0,009	226	9,3,±0,11	232	9,9,±0,027	220
7	Base+N300	8,1,±0,07	238	9,7,±0,010	242	10,2,±0,039	226
8	Base+N350	8,4,±0,10	247	10,2,±0,10	255	10,6,±0,023	235
Strongly saline							
1	Control	2,9,±0,005	100	3,6,±0,03	100	3,9,±0,012	100
2	P175K125-Base	5,2,±0,006	179	5,3,±0,08	147	5,8,±0,038	149
3	Base+N100	5,5,±0,0014	189	6,4,±0,014	178	7,0,±0,017	179
4	Base+N150	5,9,±0,03	203	7,2,±0,065	200	7,5,±0,8	192
5	Base+N200	6,2,±0,08	214	7,9,±0,080	219	8,0,±0,9	205
6	Base+N250	6,7,±0,01	231	8,2,±0,001	228	8,6,±0,5	220
7	Base+N300	7,1,±0,064	245	8,7,±0,012	241	8,9,±0,8	228
8	Base+N350	7,4,±0,09	255	9,3,±0,12	258	9,7,±0,11	249

The growth and development of plants, net productivity of photosynthesis and physiological processes in general were negatively affected by highly saline soils. For example, in all variants of the experiment the net photosynthetic productivity of cotton in the phases of budding, flowering and boll formation per g/m^2 per day was from 2.9 to 9.7. This can certainly be explained by the low leaf area and underdeveloped vegetative organs.

4 Conclusion

The present study demonstrated that soil salinity significantly reduces net photosynthetic productivity (NPP) in cotton, with the most pronounced reductions observed under moderately and strongly saline conditions. The net photosynthetic productivity of cotton varies depending on the degree of soil salinity and nitrogen fertilizer rates. As soil salinity increases, the net photosynthetic productivity of cotton decreases. The application and increase of nitrogen fertilizer rates significantly increases the net photosynthetic productivity of cotton.

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