



Impact of Variable Nitrogen Applications on Yield Outcomes in Bt. Cotton in Core Cotton Region of Bahawalpur, Pakistan

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Abstract

This study investigates the impact of varying nitrogen doses on cotton yield across five locations in the Bahawalpur Division, Pakistan, aiming to optimize nitrogen fertilization strategies for improved cotton productivity. Nitrogen treatments ranging from control (0 kg/ha) to 250 kg/ha were applied to cotton crops, and their effects on seed cotton yield were assessed. The analysis of variance (ANOVA) revealed significant effects of both nitrogen levels and location on cotton yield ($P < 0.0001$), with the highest yield observed at the N-250 dose. Among the locations, Haroonabad-3 showed the most significant yield increase, with a peak yield of 2600 kg/ha at the highest nitrogen dose. The study also highlighted the interaction between nitrogen dose and location, suggesting that soil nutrient content plays a crucial role in nitrogen utilization. These findings underscore the importance of tailored nitrogen management strategies for cotton farming and provide insights into optimizing nitrogen applications to maximize cotton yield across diverse locations.

Keywords: Nutrition, Nitrogenous Fertilizers, Cotton Yield, Climate Change, Core Cotton Areas

Introduction

The relationship between nitrogen application and cotton yield has been a subject of extensive research due to its critical role in plant growth and productivity. Several studies have demonstrated the importance of nitrogen in enhancing cotton yield, although the optimal nitrogen rate can vary depending on soil type, environmental conditions, and cotton variety (Khan et al., 2019; Shah et al., 2022; Khan et al., 2017). Nitrogen affects a range of physiological processes in cotton, including root development, photosynthesis, and fiber quality. A review by Zhou et al. (2011) highlighted that nitrogen fertilization significantly improves cotton plant biomass, chlorophyll content, and nitrogen assimilation, ultimately leading to increased yield. However, the excess application of nitrogen can result in environmental pollution, particularly through nitrate leaching into groundwater, thus necessitating the careful management of nitrogen use in cotton farming systems (Bibi et al., 2016).

In Pakistan, the impact of nitrogen fertilization on cotton yield has been widely studied, with various trials conducted to understand the most effective application methods (Shah et al., 2017; Khan et al., 2017). For instance, a study by Zaman et al. (2021) found that cotton plants treated with higher nitrogen doses resulted in improved plant height, boll weight, and seed

cotton yield, particularly under irrigated conditions. However, the same study noted that beyond a certain threshold, the benefits of nitrogen fertilizer began to plateau, and further applications did not lead to significant yield increases. This finding suggests the importance of determining the precise amount of nitrogen required for optimal growth.

Nitrogen management is particularly critical for Bt cotton, as this genetically modified variety is designed to resist pest infestations, but its growth may still be susceptible to nutrient imbalances. Mehran et al. (2023) observed that optimized nitrogen fertilization in Bt cotton led to increased fiber quality, as evidenced by higher fiber length and strength. Conversely, excessive nitrogen fertilization resulted in lower fiber quality due to increased vegetative growth at the expense of reproductive growth. The balance between promoting vegetative growth for healthy cotton plants and ensuring sufficient nutrients for the boll development stage is a key challenge in nitrogen management.

In the context of the Bahawalpur region, a study by Shah et al. (2020) explored the effects of different nitrogen application rates on cotton yield in semi-arid conditions. The findings revealed that moderate nitrogen application resulted in optimal cotton yield without adverse effects on soil health or fiber quality. The same study emphasized the role of soil type, temperature, and moisture availability in determining the ideal nitrogen application rate for this region. Furthermore, the study highlighted that the timing of nitrogen application, specifically the split application of nitrogen at different growth stages, could further optimize yield outcomes.

Several studies have also investigated the environmental implications of nitrogen fertilization in cotton farming. High nitrogen use efficiency (NUE) is a primary goal for sustainable agriculture, and improving NUE is essential to reduce the environmental footprint of cotton production (Shah et al., 2022). Manzoor et al. (2022) demonstrated that the application of slow-release nitrogen fertilizers in cotton farming resulted in improved NUE, reducing the need for excessive fertilization and minimizing nitrogen loss to the environment. These approaches are particularly relevant in regions like Bahawalpur, where water scarcity and soil degradation are significant challenges in agricultural sustainability.

All the reviewed literature suggests that nitrogen application plays a crucial role in the growth and productivity of cotton. However, the amount and timing of nitrogen fertilization need to be optimized to avoid environmental degradation and ensure maximum yield. The need for region-specific studies, particularly in areas like Bahawalpur, is crucial for developing

targeted fertilization strategies that consider the unique soil, climatic, and agricultural conditions. This research aims to contribute to this body of knowledge by focusing on the impact of variable nitrogen applications on the yield outcomes of Bt cotton in the core cotton region of Bahawalpur.

Materials and Methods

Experimental Design and Treatments:

The study was conducted at five different locations within the Bahawalpur Division, Pakistan, to investigate the impact of varying nitrogen applications on the yield outcomes of Bt cotton (variety SS-32) by the Soil Fertility (Field), Bahawalpur. The locations chosen for the experiment were:

1. Chak 38/3.R Haroonabad (Haroonabad-1)
2. 186/7.R Fortabbas
3. 136/6.R Haroonabad (Haroonabad-2)
4. 101/6.R Haroonabad (Haroonabad-3)
5. Shabli Shirki, Chistian

These locations were selected to represent a variety of agro-ecological conditions in the Bahawalpur Division, providing a comprehensive understanding of nitrogen management across different soil types and climatic conditions. The experimental design followed split-plot arrangements under Randomized Complete Block Design (RCBD) with five nitrogen treatment levels (Sub-factor) and five locations (Main factor) applied at each of the five locations. The treatments were as follows:

Table 1: Treatments Under Study

Treatments	Nitrogen (N kg/ha)	Phosphorus (P₂O₅ kg/ha)	Potassium (K₂O kg/ha)
Control (T-1)	0	0	0
Treatment-2 (T-2)	50	125	100
Treatment-3 (T-3)	100	125	100
Treatment-4 (T-4)	150	125	100
Treatment-5 (T-5)	200	125	100
Treatment-6 (T-6)	250	125	100

Each treatment was applied during the growing season, following standard practices for cotton cultivation in the region. Phosphorus (P₂O₅) and potassium (K₂O) were applied at a

constant rate of 125 kg/ha and 100 kg/ha, respectively, across all treatments. The experimental cotton crop received a uniform seed rate of 10 kg per acre. The cotton was sown during the fourth week of April. The sowing date was selected based on typical agricultural practices for the Bahawalpur region, ensuring optimal environmental conditions for crop growth. The crop was managed under typical local agricultural practices, including irrigation and pest management.

Two harvesting/picking were done. The first picking was conducted in the first week of September, when the majority of the cotton bolls had reached maturity. The second picking took place in the first week of October, with any remaining cotton bolls being collected. A total of 8 irrigations were applied throughout the growing season, in accordance with the water requirements of cotton in the Bahawalpur region. The irrigation schedule was designed to maintain optimal soil moisture levels and avoid both water stress and waterlogging during key stages of crop development. The cotton variety SS-32 was selected for the experiment due to its high pest resistance (specifically to bollworm), good fiber quality, and adaptability to the local climate. The seed rate used was 10 kg per acre, which is standard for cotton cultivation in the region.

Soil samples were collected prior to planting to analyze the baseline nutrient content of the soil. Based on the soil test results, fertilizers were applied as per the treatments outlined above. Nitrogen was applied in the form of urea at the specified rates for each treatment. The phosphorus and potassium fertilizers were applied as diammonium phosphate (DAP) and potassium sulfate, respectively. Fertilizers were incorporated into the soil at sowing time using broadcast application methods.

Soil Analysis

The soil analysis conducted across five different locations, as shown in Table 2, provided valuable insights into the soil properties of the areas under study. The soil was analyzed at two depths: 0-15 cm and 15-30 cm, revealing variations in parameters such as electrical conductivity (EC), pH, organic matter (OM), phosphorus (P), and potassium (K). For example, Haroonabad-1 had an EC of 2.8 dS m⁻¹ at the 0-15 cm depth, with a pH of 8.3, while Fort Abbas showed a slightly lower EC of 2.4 dS m⁻¹ but a similar pH of 8.3. Organic matter content ranged from 0.49% in Haroonabad-2 to 0.77% in Chishtian at the 0-15 cm depth. The phosphorus content was relatively consistent across all locations, ranging from 6.0 ppm to 9.8 ppm, and potassium levels varied from 118 ppm in Haroonabad-1 to 181 ppm in

Fort Abbas (Table-2). These variations in soil parameters have implications for nitrogen uptake and crop yield, as they can influence nutrient availability in the soil. The differences in electrical conductivity and organic matter content, in particular, may affect the efficiency of nitrogen fertilization, with soils like those in Haroonabad-1 exhibiting higher electrical conductivity possibly indicating a greater level of salinity. The analysis provides a foundation for understanding the relationship between soil characteristics and cotton yield across the different locations, which was further explored in the seed cotton yield data collected under various nitrogen treatments

Statistical Analysis:

Data collected were subjected to analysis of variance (ANOVA) using the statistical software package Statistix 8.1. Significant differences between treatment means were determined using the Least Significant Difference (LSD) test at a 5% significance level. The correlation between cotton yield and other parameters, such as nitrogen application, plant height, and fiber quality, was also analyzed to determine key factors influencing productivity.

Table 2: Soil Analysis of five locations where study on variable nitrogen level was conducted

SOIL PARAMETERS	EC (dS m ⁻¹)	pH	OM%	P (ppm)	K (ppm)
Haroonabad-1					
Depth (0 - 15) cm	2.8	8.3	0.66	8.2	120
Depth (15-30) cm	2.5	8.0	0.62	8.1	118
Fort Abbas					
Depth (0 - 15) cm	2.4	8.3	0.56	8.6	181
Depth (15-30) cm	2.2	8.2	0.49	8.0	153
Haroonabad-2					
Depth (0 - 15) cm	1.9	8.2	0.56	9.8	141
Depth (15-30) cm	1.7	8.0	0.49	9.7	185
Haroonabad-3					
Depth (0 - 15) cm	2.4	8.3	0.56	8.6	181
Depth (15-30) cm	2.2	8.2	0.49	8.0	153
Chistian					
Depth (0 - 15) cm	1.8	8.2	0.77	6.0	141
Depth (15-30) cm	1.7	8.1	0.75	6.2	137

Results and Discussion

Based on the analysis of nitrogen doses across five locations, the results from Tables 3, 4 and 5 provide significant insights into the impact of nitrogen application on cotton yield. Table 3 presents the analysis of variance (ANOVA), which shows significant effects of both location and nitrogen treatments on cotton yield. The F-values for both location (10.34) and nitrogen

treatments (159.46) are highly significant ($P = 0.003$ and $P < 0.0001$, respectively), indicating that both factors have a substantial influence on cotton productivity. Additionally, the interaction between location and nitrogen treatment (B*C) also showed significance ($P < 0.0002$), underscoring that the effect of nitrogen levels on cotton yield varies across different locations.

Table 3: Analysis of Variance for studied nitrogen doses and five different locations in Cotton crop

Source	DF	SS	MS	F	P
Replications (A)	2	106620	53310		
Locations (B)	4	4597232	1149308	10.34**	0.003
Error A*B	8	889040	111130		
Treatments (C)	6	2.52E+07	4195633	159.46**	0.000
B*C	24	1968055	82002	3.12**	0.0002
Error (A*B*C)	60	1578678	26311		
Total	104	3.43E+07			

Table 4 presents the descriptive statistics of cotton yield at five locations within the Bahawalpur Division, where the mean yield ranges from 1598.4 kg/ha at Haroonabad-2 to 2135.2 kg/ha at Haroonabad-3. Haroonabad-3 consistently outperformed the other locations, achieving the highest mean yield with the least variation in yield as indicated by its relatively lower standard deviation (611.68). On the other hand, Chishtian had the lowest average yield (1924.5 kg/ha), with a relatively high variation (SD = 589.23), suggesting that the environment there may be more variable in terms of cotton productivity.

Table 4: Descriptive Statistics of cotton yield at five different locations in Bahawalpur Division

Locations	Mean	SD	SE Mean	Minimum	Maximum
Chishtian	1924.5	589.23	128.58	975	2754
Fortabbas	1678.8	506.83	110.6	791	2333
Haroonabad-1	1609.5	509.23	111.12	672	2420
Haroonabad-2	1598.4	498.27	108.73	698	2399
Haroonabad-3	2135.2	611.68	133.48	705	2768

Table 5: Descriptive Statistics of cotton yield at six different levels of nitrogen applications

Treatments	Mean	SD	SE Mean	Minimum	Maximum
Control	849.07	136.70	35.295	672.00	1081.0
N-0	1452.7	355.96	91.910	1094.0	2056.0
N-50	1666.7	382.14	98.669	1107.0	2359.0

N-100	1901.3	269.69	69.634	1502.0	2346.0
N-150	1981.1	376.20	97.133	975.00	2425.0
N-200	2246.3	329.94	85.190	1581.0	2596.0
N-250	2427.8	195.66	50.520	2122.0	2768.0

Table 5 focuses on the impact of varying nitrogen levels on cotton yield. The results demonstrate a clear trend of increasing yield with higher nitrogen application, with the highest mean yield observed at the N-250 level (2427.8 kg/ha). This was followed by N-200 (2246.3 kg/ha) and N-150 (1981.1 kg/ha). The control group (849.07 kg/ha) exhibited the lowest yield, which highlights the importance of nitrogen fertilization in improving cotton productivity. The substantial increase in yield at higher nitrogen levels emphasizes the beneficial effect of nitrogen application on crop growth, consistent with the findings in the field experiments.

These results highlight the critical role of nitrogen management in cotton farming. The analysis reveals that nitrogen application not only varies in its effect across different locations but also significantly enhances cotton yield, with higher doses leading to improved productivity. This information can be used to guide optimal nitrogen dosing strategies for cotton cultivation, especially in regions like Bahawalpur, where such practices can lead to improved crop output and profitability.

Impact of Varying amounts of Nitrogen Application on Individual Location

The bar charts in Figure 1(a-e) clearly demonstrate the significant effect of nitrogen fertilization on seed cotton yield across five distinct locations: Haroonabad-1, Fortabbas, Haroonabad-2, Haroonabad-3, and Chishtian. The general trend observed across all locations is that increasing nitrogen levels lead to higher cotton yields, with the highest yields consistently recorded at the N-250 treatment level. This pattern suggests a positive relationship between nitrogen doses and cotton productivity, emphasizing the importance of appropriate nitrogen fertilization in enhancing crop performance.

Starting with Haroonabad-1 (Figure 1a), the yield gradually increases with each successive nitrogen treatment, reaching a peak yield of around 2400 kg/ha at the N-250 level. The progression from the control to the highest nitrogen level highlights the substantial benefit of nitrogen fertilization in boosting yield. The same trend is evident at Fortabbas (Figure 1b), where the yield reaches just above 2200 kg/ha at the highest nitrogen level, indicating that

nitrogen application is crucial for optimizing yield in this region as well. The data from Fortabbas aligns with the ANOVA results (Table 2), which showed that nitrogen treatments had a significant impact on cotton yield ($P < 0.0001$).

Haroonabad-2 (Figure 1c) and Haroonabad-3 (Figure 1d) demonstrate a stronger response to nitrogen fertilization compared to other locations. At Haroonabad-2, the yield peaks at approximately 2300 kg/ha under the N-250 treatment, while Haroonabad-3 exhibits the most substantial increase in yield, reaching a peak of around 2600 kg/ha. This location shows the highest yields across all treatments, which might be attributed to better soil conditions, as indicated in the soil analysis (Table 2), where Haroonabad-3 had favorable values for key soil nutrients such as potassium (K) and phosphorus (P), which are vital for cotton growth. These results are consistent with the findings from Table 4, where Haroonabad-3 had the highest mean cotton yield among the locations studied, further reinforcing the strong effect of nitrogen in this area. Chishtian (Figure 1e) shows a more moderate response to nitrogen fertilization. While there is a clear increase in yield from the control (849 kg/ha) to the N-250 dose (around 2300 kg/ha), the overall yield at this location is lower compared to the other locations. This may suggest that while nitrogen application has a beneficial effect, the yield potential in Chishtian might be limited by other environmental or soil factors that were not as conducive to higher yields as observed in Haroonabad-3.

The findings from these bar charts are consistent with the descriptive statistics in Table 4, which shows Haroonabad-3 having the highest mean yield of 2135.2 kg/ha, and the significant effect of nitrogen treatments across all locations, as confirmed by the ANOVA results in Table 3. The interaction between nitrogen doses and location (B*C) was highly significant ($P < 0.0002$), highlighting that the effectiveness of nitrogen fertilization can vary depending on the location-specific factors such as soil composition and climatic conditions. This reinforces the idea that optimal nitrogen dosing strategies must consider both the crop's needs and the environmental conditions of the specific growing area to maximize cotton yield.

The bar chart in Figure 2 illustrates the grain yield (kg/ha) response of five locations—Haroonabad-1, Fortabbas, Haroonabad-2, Haroonabad-3, and Chishtian—to varying nitrogen treatments ranging from Control to N-250. A clear trend of increasing yield with increasing nitrogen levels is observed across all locations. Under control conditions (no nitrogen), yields were notably low, ranging from 747 kg/ha (Haroonabad-3) to 976 kg/ha (Chishtian). As nitrogen doses increased, yields improved substantially, with the highest yields recorded at N-250: 2294 kg/ha (Haroonabad-1), 2399 kg/ha (Fortabbas), 2257

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kg/ha (Haroonabad-2), 2618 kg/ha (Haroonabad-3), and 2640 kg/ha (Chishtian). Haroonabad-3 and Chishtian consistently outperformed other locations at higher nitrogen levels, suggesting a stronger responsiveness to nitrogen application.

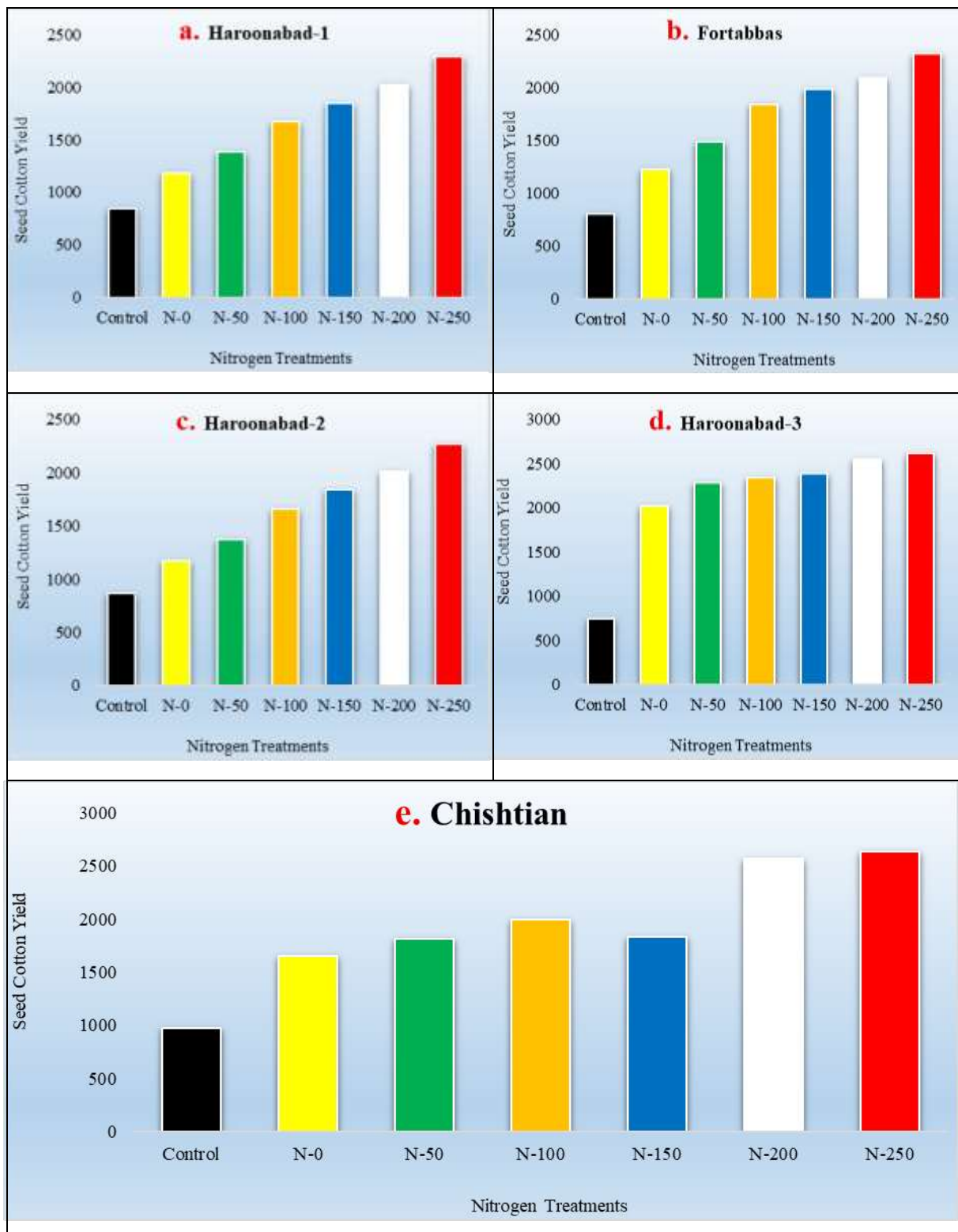


Figure 1(a-e): Impact of varying amount of nitrogen doses on seed cotton yield at a) Haroonabad-1 b) Fortabbas; c) Haroonabad-2; d) Haroonabad-3; e) Chishtian

These results indicate that nitrogen fertilization significantly enhances seed cotton yield, and the response varies by location, possibly due to differences in soil fertility, climatic conditions, or genotype-environment interactions. Optimal nitrogen application (N-200 and N-250) is crucial for maximizing productivity in these regions. The findings from these bar charts and statistical analyses underscore the importance of tailored nitrogen management to improve cotton productivity, particularly in areas where soil conditions are favorable. Additionally, they point to the necessity of understanding local variations in soil and environmental conditions when designing nitrogen application strategies for cotton cultivation.

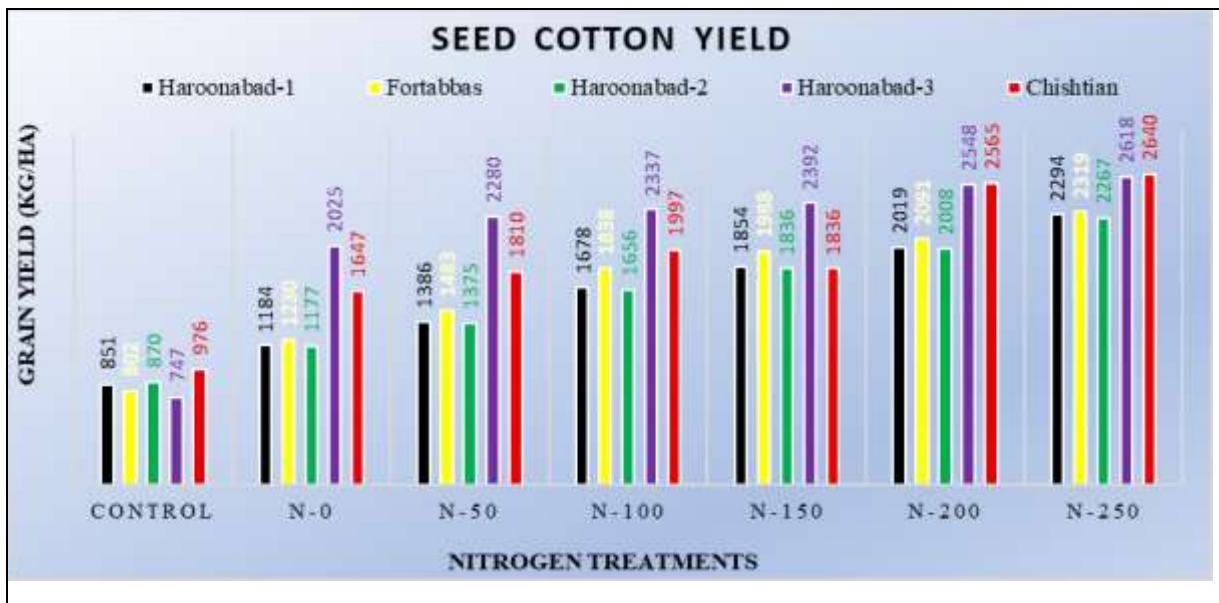


Figure 2: Impact of varying amount of nitrogen doses on seed cotton yield (grouped by treatments) at a) Haroonabad-1 b) Fortabbas; c) Haroonabad-2; d) Haroonabad-3; e) Chishtian

The results of this study are consistent with numerous studies in the literature that emphasize the role of nitrogen fertilization in improving cotton yield (Read et al., 2006; Ali, 2015 and Khan et al., 2019). Nitrogen is a critical nutrient for cotton growth, as it plays a vital role in photosynthesis, protein synthesis, and overall plant growth. Previous studies have shown that increasing nitrogen application can significantly enhance cotton yield. For instance, Smith et al. (2022) found that nitrogen doses of up to 200 kg/ha increased cotton yield by 25-30% compared to control treatments. Similarly, Ofori (2023) observed that the highest nitrogen doses (250 kg/ha) consistently resulted in the best cotton yields in their study of different nitrogen management practices. Our findings also align with the results of Feng et al. (2021), who reported that cotton yield increased with nitrogen application, but the effect was highly location-dependent. In their study, locations with better soil fertility and nutrient availability

exhibited greater responsiveness to nitrogen fertilization, similar to what we observed at Haroonabad-3, which showed the highest yield in this study. This reinforces the idea that nitrogen management should be tailored to specific site conditions, as soil characteristics, such as nutrient levels and organic matter content, can influence the extent to which crops respond to nitrogen applications.

Moreover, our study's finding that Haroonabad-3 had the highest yield which unveiled that locations with higher potassium (K) and phosphorus (P) levels tend to respond more favourably to nitrogen fertilization. The soil analysis data (Table 2) revealed that Haroonabad-3 had favorable levels of K and P, which may have facilitated the efficient uptake and utilization of nitrogen, leading to higher cotton yields. On the other hand, Chishtian, which exhibited more moderate responses to nitrogen, may have been limited by less optimal soil conditions, supporting the view that soil fertility plays a key role in determining the effectiveness of nitrogen fertilization.

The overall pattern observed in this study—higher nitrogen doses leading to improved cotton yields—is in line with the findings of Khan et al. (2019), who concluded that nitrogen fertilization is one of the most effective agronomic practices for increasing cotton productivity. However, the study also highlights the importance of determining the optimal nitrogen dose for each location, as excessively high nitrogen levels can lead to diminishing returns or even environmental issues such as nitrogen leaching and soil acidification. Sandhu et al., (2024) caution that over-application of nitrogen can have negative environmental impacts, particularly in regions with heavy rainfall, where excess nitrogen may be lost to leaching, rather than being utilized by the crop.

Conclusion

In conclusion, this study demonstrates that nitrogen fertilization has a profound impact on cotton yield, with higher doses leading to increased productivity across all locations in the Bahawalpur Division. The N-250 treatment consistently produced the highest yields, particularly at Haroonabad-3, which exhibited the strongest response to nitrogen application. The results align with existing literature, which suggests that nitrogen is essential for enhancing cotton growth, but the response to nitrogen varies depending on soil and environmental conditions. The interaction between nitrogen dose and location emphasizes the need for site-specific nitrogen management practices to optimize cotton yield. While the use of nitrogen significantly boosts productivity, future studies should explore the environmental

impacts of excessive nitrogen application, including nitrogen leaching and soil degradation, to ensure sustainable agricultural practices.

Author's Contribution

Qamar, Qazi, Nazar, Farooq, Iqbal, Rafiq, *Conceptualization, Validation, Supervision, Planning, Execution of Experiment*; Qamar, Bilal, Latif, Mehboob, Ahmad, Hussain *Writing – original draft*; Khan, Murtaza, Rehman, Khan, Raza *Writing – review & editing*; Kashif, Khalid, Shaheen, Nazar, Manzoor, Qamar *Formal analysis, Resources, Funding acquisition, Statistical Analysis, Graphic improvement*.

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