

## Effect of Irrigation Regimes and Nitrogen Levels on Growth and Yield of Cotton Genotypes Under Climate of Multan

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### ABSTRACT

Nitrogen use efficiency (NUE) and water scarcity are the biggest problems in the agriculture sector. These problems can arise in arid and semi-arid areas with water scarcity and low soil fertility. Cotton in south Punjab faces these problems during growth and development stages, so the yield results are lower than in other cotton-producing regions. This study was designed to assess the potential of different cotton genotypes grown on various water and nitrogen (N) applications. This study involves seven cotton crop genotypes with three irrigation levels, i.e., 18, 13, and 9 irrigations with N application at 200, 250, and 300 kg ha<sup>-1</sup> under randomized complete block design (RCBD) factorial arrangement with three replications of each treatment. The data regarding plant growth, yield, and physiology was collected. The results indicated that Genotype IUB-13 showed a higher N uptake of 0.84% among the other seven genotypes tested at (T2). Among the seven genotypes tested, NAIB-878 demonstrated a significantly higher value of lint weight 1200 g in block-1 and T2. The finding of this study concluded that higher N levels under deficit irrigation could help to reduce the yield gaps by increasing the growth of cotton genotypes under the climatic conditions of Multan.

**Keywords:** water scarcity, nitrogen use efficiency, climate change, greenhouse gas emissions, cotton.

### INTRODUCTION

In most intensive agricultural production systems up to 75% of the nitrogen (N) applied to the field is lost by leaching into the soil [1]. The fundamental concept of nitrogen use efficiency (NUE) revolves around maximizing seed yield per unit of available N. NUE encompasses two critical components, i.e., Nitrogen

Uptake Efficiency (NUpE) and Nitrogen Utilization Efficiency (NutE) which characterizes the capacity of plants to capture N from the soil efficiently. At the same time, NUtE measures the ability of plants to utilize the absorbed N to produce high-quality seeds effectively [2]. By optimizing NUpE and NUtE, agricultural systems can enhance N utilization, improve crop yields and sustainable agricultural practices. Crop fertilization with synthetic N-based fertilizers has improved crop yields in modern agriculture, but only 30 – 50% of the 109 Tg of fertilizer-N annually applied is used by the crops [3]. The remaining N is converted into the forms that cause soil, water, and atmospheric pollution. As N-pollution is a pressing global problem, improving the NUE of N-fertilizers in agriculture [4]. The leading cause of N leaching into the soil, inefficient irrigation, is one of the top contributors [5]. Along with N application and NUE, water scarcity is also a problem in most of the regions in the world, and the situation is worsening in

### Article History

Received: September 15, 2023, Accepted: November 11, 2023, Published: December 14, 2023



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Asia, especially in arid and semi-arid regions such as Pakistan. Agricultural water consumption primarily contributes to human freshwater consumption [6]. Agricultural water consumption significantly contributes to freshwater usage in many areas, making it essential to understand effective water utilization and consider crop trading to alleviate water scarcity [7]. Deficit irrigation (DI) is an irrigation method that optimally allocates crop irrigation time or irrigation amount owing to insufficient water resources. This technique has been shown to maintain reasonably higher crop yields, especially cotton yield, and improve water use efficiency (WUE) by only applying the required water quantity at a suitable time [8]. This water technology allows farmers to increase WUE. While DI can improve WUE without incurring severe yield reductions, growers implementing DI require precise knowledge of crop response to drought stress at different crop phenological stages to reduce their economic losses [9]. The regulated time and degree of DI play a pivotal role in allowing DI implementation and determining its application effectiveness [10]. Cotton (*Gossypium hirsutum* L.) is produced for lint, vital in the textile industry as a raw material for cloth manufacturing [11]. Its production and consumption are increasing daily. Pakistan is the world's 5th biggest cotton producer, accounting for about 0.6% of the GDP and 2.4% of agricultural value added [12]. But now, cotton cultivation has been reduced and substituted by other opposing crops such as sugarcane, maize, potato, and rice. In 2021 – 22, the cultivated area of cotton crops decreased from 2,079 to 1,937 thousand hectares (6.8%). Against the previous year's cotton production increased from 7.064 to 8.329 million bales (17.9%) because of conducive weather conditions, smooth input supply, and better crop management practices (GOP 2021 – 22). Due to water scarcity, limited precipitation, and high rates of evapotranspiration, arid and semiarid regions like Multan face more severe challenges regarding water shortages. Multan is in the Punjab, and its climate plays a significant role in cotton cultivation. The temperature of Multan exceeds 40°C in cotton season, which is suitable for cotton, which requires high temperatures to thrive and grow well. Moreover, the availability of diverse irrigation infrastructure in

Multan supports the growth and makes it vital for the region. As per the report of first estimate of cotton crop for the year 2022-23, it is cultivated on an area of 771 acres with a total production of 2,528,764 bales in Multan division (*Production Plans / Extension & Adaptive Research*, 2022). Despite Pakistan's high international ranking in cotton production, the average return remains much below genomic potential [13]. Cotton's nutrient efficiency may be the plant's capacity to transfer nutrition from reproductive to vegetative structure systems. In view of all the above problems regarding NUE, water scarcity, and cotton's importance in Pakistan's GDP, there is a need to adapt and develop strategies to produce cotton in semi-arid and arid environments and screening of cotton genotypes adapted to local conditions. So, this study involved seven cotton genotypes grown under reduced N and water levels. The objectives were to a) produce cotton crop under reduced water and urea application, b) screen out cotton crop genotypes with high NUE under deficit irrigation, and c) study the effects of reduced nitrogen and irrigation application on crop growth and yield.

## MATERIAL AND METHODS

### Site Description and Experimental Design

The study was conducted in the MNS-University of Agriculture research area, Multan, Punjab, Pakistan (30.1601858586, 71.4501816271, Figure 1). The climate of this region is arid to semi-arid. The total area of the experiment was 1.125 acres (9 Kanals), which was subdivided into three blocks. This experiment was laid out during Kharif season of 2022 in a randomized complete block design (RCBD) under a factorial arrangement with three replications. Seven cotton genotypes (CIM-668, IUB-13, BS-15, CKC-6, UAM-20, MNH-1020, and NIAB-878) were sown on 28 April 2022 and harvested on 2 November 2022. The seeds were planted with a plant-to-plant distance of 1 foot and row to row distance of 2.5 feet. Three irrigation levels were applied, i.e., 9, 13, and 18 irrigations. The urea was used as N and considered as a treatment dose for the crop, i.e., T1: N at 200 kg ha<sup>-1</sup>, T2: N at 250 kg ha<sup>-1</sup>, and T3: N at 300 kg ha<sup>-1</sup> were applied in the irrigation mentioned above levels. The crop was harvested after 180 days of sowing in the end of kharif season.

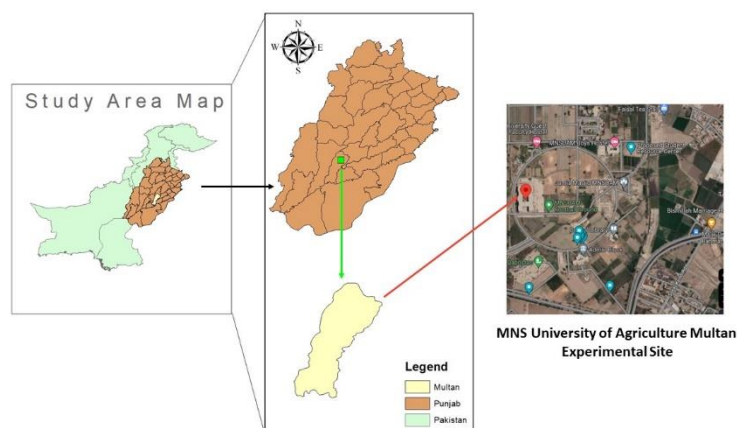


Figure 1. Description of study area.

### Soil sample collection, processing, and analysis

Soil samples were taken from each block using a random sampling method at 0 – 15, 15 – 30, and 30 – 45 cm soil depths before crop sowing. The samples were brought to the analytical laboratory of the institute for further processing and analysis. The samples were sieved through a 2mm sieve and dried in shade. After this, the physico-chemical attributes of the soil were analyzed according to the well-established protocols. The electrical conductivity

and pH of soil samples were determined by making the ratio of soil and water (1:1). The organic matter of soil was determined by the procedure of Walkley et al., (1947) [21]. The macro-nutrients, i.e., N analyzed on automatic distillation system DNP series, phosphorus (P) on Cecil Aquarius CE 7400S, and potassium (K) was analyzed on BWB XP Flame Photometer by using protocols described by Olsen [14], Mehlich [15], and respectively (Table 1).

Table. 1 Physiochemical attributes of the experimental site

Block	Depth (cm)	OM (%)	pH	EC (dsm <sup>-1</sup> )	N (%)	P (mg kg <sup>-1</sup> )	K (mg kg <sup>-1</sup> )	Zn (mg kg <sup>-1</sup> )	Fe (mg kg <sup>-1</sup> )	B (mg kg <sup>-1</sup> )
1	15	0.52	8.6	1.12	0.02	8.7	120	0.8	5.68	0.65
	30	0.51	8.7	1.06	0.05	8.7	121	1.43	6.12	0.69
	45	0.52	8.4	2.15	0.04	9.21	332	0.86	6.17	0.78
2	15	0.69	8.3	1.15	0.02	10.2	121	0.79	5.41	0.83
	30	0.62	8.2	1.12	0.03	9.12	134	0.77	6.21	0.62
	45	0.57	8.2	0.99	0.03	10.31	124	2.12	5.12	0.78
3	15	0.66	8.1	1.13	0.02	10.1	120	0.69	4.33	0.72
	30	0.60	8.2	1.30	0.91	8.91	131	0.91	5.21	0.81
	45	0.54	8.6	1.04	0.02	8.42	122	0.81	4.43	0.73

### Plant growth, yield, and physiology

The data about plant growth was taken at crop maturity, while physiological data was taken using a portable photosynthetic system, i.e., CIRUS-3. Water use efficiency (kg<sup>-1</sup>ha<sup>-1</sup>mm<sup>-1</sup>), transpiration rate (mmol H<sub>2</sub>O m<sup>-2</sup>s<sup>-1</sup>), photosynthetic rate (μmol CO<sub>2</sub> m<sup>-2</sup>s<sup>-1</sup>), and chlorophyll contents (mg g<sup>-1</sup>) Fresh Weight (FW) were recorded. The physiological attributes will ensure the efficiency of treatment under deficit irrigation regimes.

### Nitrogen Use Efficiency and Phosphorus Analysis

The NUE measures how efficiently the N was utilized by plants applied at specific rates. The NUE, according to the applied rates in this experiment, was calculated using the following formula.

$$NUE (\%) = \frac{N_{utilized}}{N_{applied}}$$

For N output calculation, grain yield and N were calculated. Moreover, P analysis was conducted by following Ab-DPTA method of samples preparation and the spectrophotometer at 470nm wavelength.

### Statistical analysis and data presentation tools

The experiment was laid out in RCBD under three factors with three replications of each treatment. The data collected was analyzed through analysis of variance (ANOVA) using Statistix v 8.10 (Analytical Software, FL, USA), and Microsoft Excel (Microsoft Corporation, USA) was used for data presentation. Levels of significance were conceived through the least significant difference (LSD) test at  $p \leq 0.05$ .

**RESULTS**

**Plant growth, yield, and physiology**

**Plant height (cm)**

The main effects of cotton varieties, irrigation, and N were highly significant at a  $p < 0.05$ . The results of all treatments on plant height are presented in Figure 2. The plant height was maximum observed in CKC-6, which was 139 cm under block-2 (irrigation level 13)

and treatment-2 (N rates  $250 \text{ kg ha}^{-1}$ ), and a minimum value was observed in genotype CIM- 663. Its value was 52 cm under block-2 (irrigation level 13) and treatment-2 (N doses  $250 \text{ kg ha}^{-1}$ ). The results provide valuable insights into the variations among the studied genotypes and N and irrigation levels on observed plant height, highlighting the significance of genotype in influencing plant height.

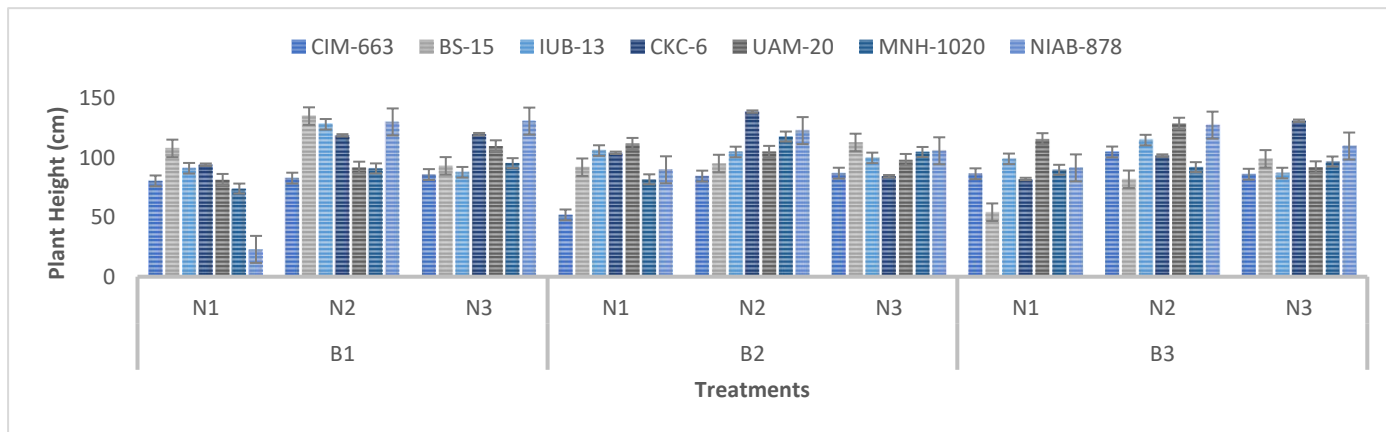


Figure 2. Effect of reduced irrigation levels and nitrogen different N doses on cotton plant height. LSD All-Pairwise Comparisons Test of plant height cm for Genotype \* Treatment \* block. B1= 18 Irrigation level, B2= 13 Irrigation level, B3= 9 Irrigation level.

**Number of monopodial branches**

The dataset analyzed in this study consisted of seven distinct genotypes, and the statistical analysis revealed that the observed differences among the genotypes were not statistically significant ( $p > 0.05$ ). This investigation examined the potential relationship between genotype and a monopodial branch (Figure 3).

The results indicate that, within the parameters of this study, genotype does not play a significant role in influencing the trait under consideration. Other factors in understanding the complexity of monopodial branch associations suggest that environmental conditions or genetic interactions may substantially impact the observed monopodial branches.

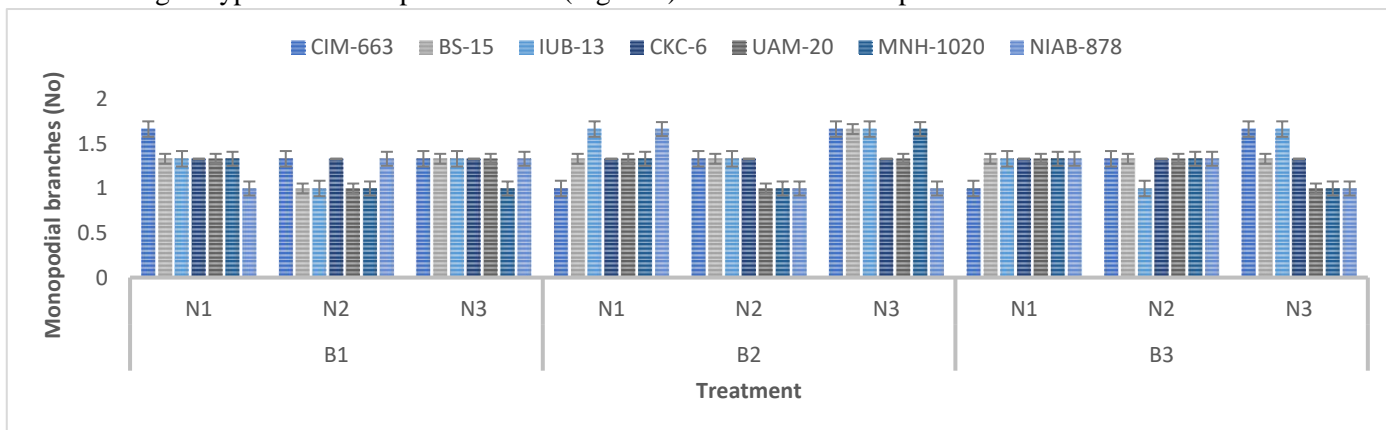


Figure 3. Effect of reduced irrigation levels and nitrogen different N doses on monopodial branches of cotton. LSD All-Pairwise Comparisons Test of monopodial branches for Genotype \* Treatment \* block. B1= 18 Irrigation level, B2= 12 Irrigation level, B3= 9 Irrigation level.

**Number of sympodial branches**

The dataset analysis focused on the number of sympodial branches and revealed that it was highly significant with ( $p\text{-value} < 0.05$ ), which is represented in Figure 4. Genotype CKC-6 exhibited the highest average number of sympodial branches, with a value of

26.66 observed in block-1 (irrigation 18) and Treatment-2 (N doses  $250 \text{ Kg ha}^{-1}$ ). On the other hand, genotype CIM-663 had the lowest average number of sympodial branches, with a value of 1.33 observed in block-3 (irrigation 9) and treatment-3 (N doses  $300 \text{ Kg ha}^{-1}$ ). These findings highlight the substantial impact of

genotype and irrigation levels on the development of sympodial branches. The significant variation in the number of sympodial branches among the genotypes suggests that genotype plays a crucial role in influencing these sympodial branches. Genotype CKC-6, characterized by its high number of sympodial units, demonstrates a genetic propensity for enhanced

branching. In contrast, genotype CIM-663 exhibits fewer sympodial branches, indicating a different genetic predisposition. These findings emphasize the importance of considering genotype-specific effects when studying sympodial branching and suggest that genetic factors play a significant role in determining the observed variations in sympodial branch development.

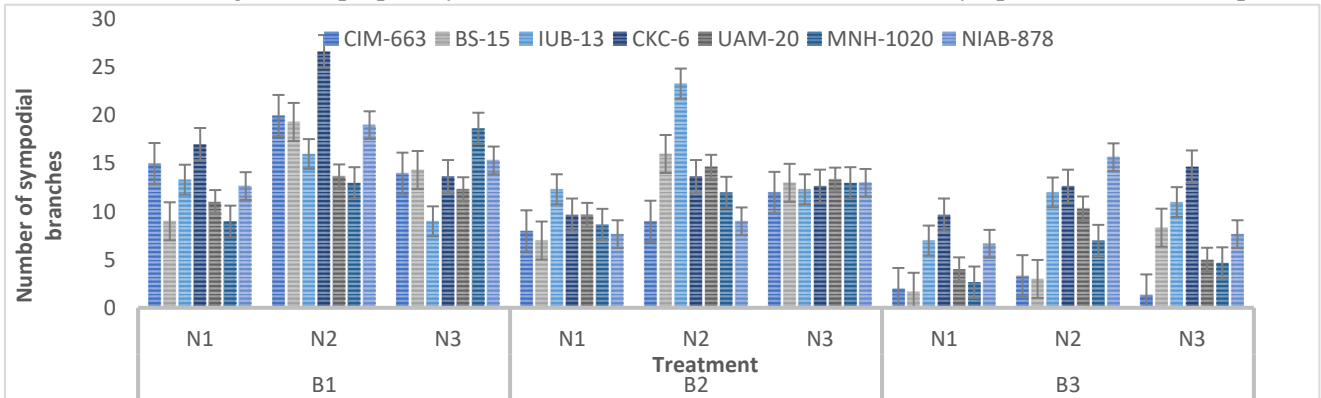


Figure 4. Effect of reduced irrigation levels and nitrogen different N doses on sympodial branches of cotton. LSD All-Pairwise Comparisons Test of sympodial branches for Genotype \* Treatment \* block. B1= 18 Irrigation level, B2= 13 Irrigation level, B3= 9 Irrigation level.

**Number of Bolls per plant**

The main effects of varieties, irrigation, and N application rates were highly significant, with a  $p \leq 0.05$ . Figure 5 presented the data regarding the number of bolls, revealing that the CKC-6 genotype displayed the highest boll count of 36 under block-1 and treatment-3. Conversely, the BS-15 genotype exhibited the lowest boll count of 3 under block-3 (irrigation level 9) and treatment-1 (N doses 200 kg ha<sup>-1</sup>). These findings provide valuable insights into the variations among the genotypes and treatment and show that N rates play an important role and impact on the observed

trait, highlighting the significant influence of genotype, treatment, and irrigation levels on the number of bolls, yield, and quality. These findings provide crucial insights for agricultural practitioners and breeders, highlighting the genotypic variations, N rates, and irrigation levels in boll production and emphasizing further exploration to understand the underlying mechanisms driving these differences. By unraveling the factors contributing to higher boll counts, breeders can develop improved genotypes that have the potential to enhance overall cotton.

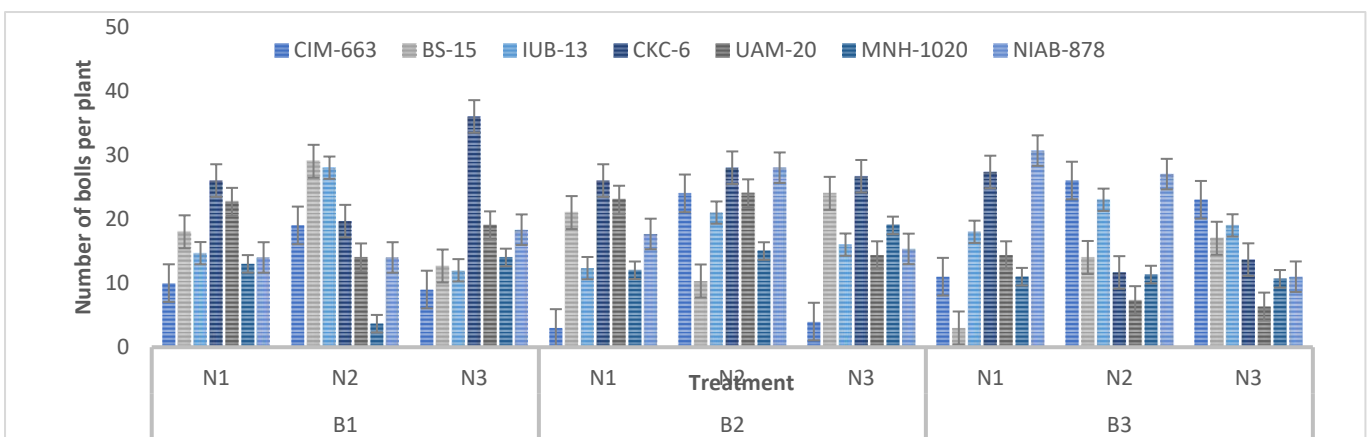


Figure 5. Effect of reduced irrigation levels and nitrogen different N doses on the number of cotton bolls. LSD All-Pairwise Comparisons Test of the number of bolls for Genotype \* Treatment \* block. B1= 18 Irrigation level, B2= 13 Irrigation level, B3= 9 Irrigation level.

**Number of squares per plant**

The dataset analysis focused on the number of squares and revealed that it is highly significant ( $p < 0.05$ ), represented in Figure 6. Genotype MNH-1020 exhibited the highest average number of digits of squares, with a value of 68 observed in block-3 (irrigation 9) and treatment-2 (N doses 250 kg ha<sup>-1</sup>). On the other hand, genotype MNH-1020 had the lowest average number of sympodial branches, with a value of 11.667 observed in block-1 (irrigation 18) and (N doses 200 kg ha<sup>-1</sup>) and Treatment-1, shown in Figure 6. These findings highlight the substantial

impact of genotype and deficit irrigation on the development of the number of squares. The significant variation in the number of squares among the genotypes suggests that irrigation level is crucial in influencing this number. Genotype MNH-1020, characterized by its high number of squares, demonstrates irrigation and N-level for enhanced squares. In contrast, the same genotype MNH-1020 exhibits fewer squares, indicating different irrigation and treatment.

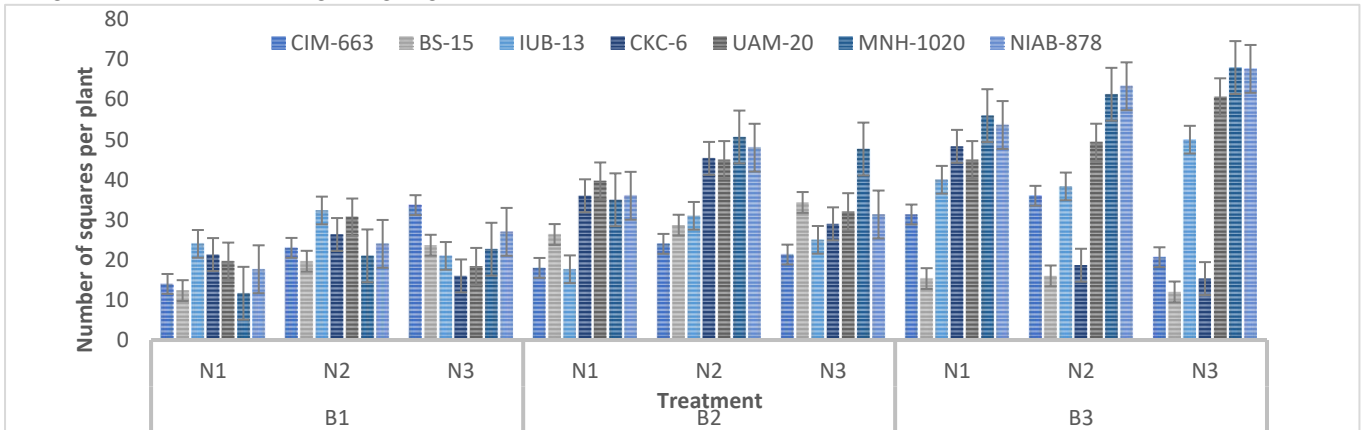


Figure 6. Effect of reduced irrigation levels and nitrogen different N doses on several cotton squares. LSD All-Pairwise Comparisons Test of several squares for Genotype \* Treatment \* block. B1= 18 irrigation level, B2= 13 irrigation level, B3= 9 irrigation level

**Total number of boll weights (g)**

The data analysis demonstrated that the results were statistically significant, with a  $p$ -value  $< 0.05$ , as shown in Figure 7, indicating the observed differences in total boll weights among the seven genotypes. NAIB-878 displayed a higher total weight compared to the seven genotypes. This can be observed in the provided data, where NAIB-878 exhibited a total boll weight of 2533.33 g in block-2 (13 irrigation applied) and treatment-3 (300 kg N ha<sup>-1</sup> applied) presented in

Figure 7. This suggests that the NAIB-878 genotype positively influences the overall boll weight under conditions. In contrast, another genotype, CKC-6, showed a lower total boll weight of 443.3 g in block-3 (9 irrigation) and treatment-1 (200 kg N ha<sup>-1</sup> applied). This indicates that CKC-6 may have a lower boll weight accumulation or growth capacity in the tested conditions.

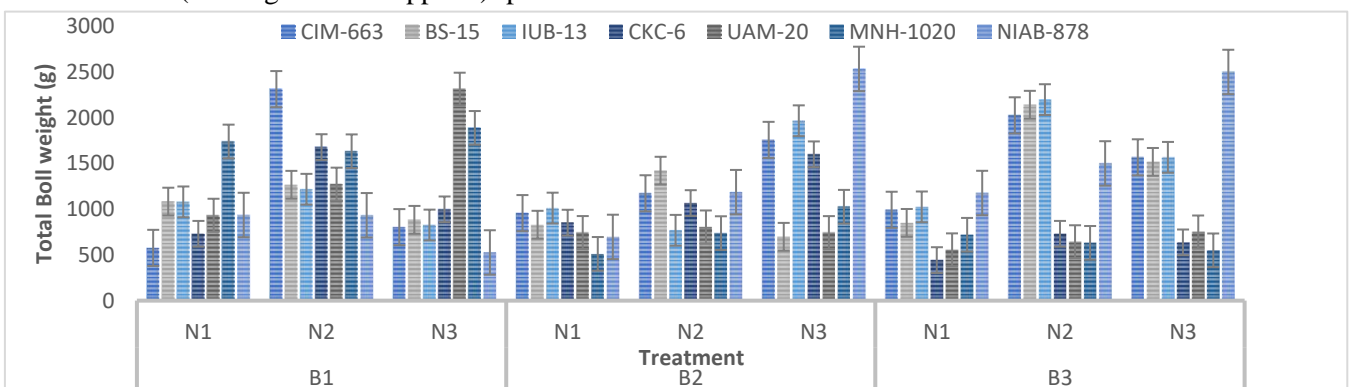


Figure 7. Effect of reduced irrigation levels and different N doses on the total number of total weights of cotton. LSD All-Pairwise Comparisons Test of total weight for Genotype \* Treatment \* block. B1= 18 Irrigation level, B2= 13 Irrigation level, B3= 9 Irrigation level.

**Boll weight (g)**

The data analysis revealed that the results were statistically significant, with a  $p < 0.05$ , as shown in Figure 8, indicating the differences in boll weight among the seven genotypes. NIAB-878 displayed a higher boll weight compared to the seven genotypes. This can be observed in the provided data, where NIAB-878 exhibited a boll weight of 101 g in block-1 (18 irrigation applied) and treatment-2 (250 kg N ha<sup>-1</sup>

applied), presented in Figure 8. This suggests the NIAB-878 genotype positively influences the overall bolls weight under the given conditions. In contrast, another genotype, UAM-20, showed a lower bolls weight of 26 g in block-3 (9 irrigation) and treatment-1 (200 kg N ha<sup>-1</sup> applied). This indicates that UAM-20 may have a lower capacity for weight accumulation or growth in treatment-1 and block-3.

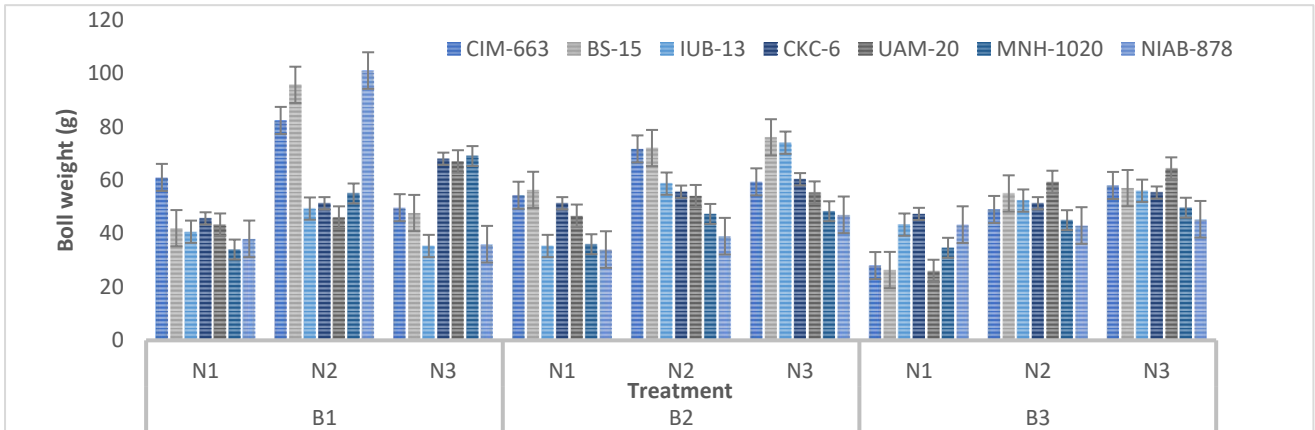


Figure 8. Effect of reduced irrigation levels and different N doses on bolls weights of cotton. LSD All-Pairwise Comparisons Test of bolls weight for Genotype \* Treatment \* block. B1= 18 Irrigation level, B2= 13 Irrigation level, B3= 9 Irrigation level.

**Lint weight (g)**

The data from the experiment revealed statistically significant results with a  $p$ -value  $< 0.05$ , as shown in Figure 9. Among the seven genotypes tested, NAIB-878 demonstrated a significantly higher value of lint weight 1200 g in block-1 (18 irrigation levels applied) and treatment-2 (250 kg N ha<sup>-1</sup>). This indicates that NAIB-878 exhibited superior lint weight to other genotypes under these conditions. The substantial increase in lint weight associated with NAIB-878 suggests its potential for enhancing cotton yield in similar environments or management practices. On the other hand, block-3 (9 irrigation levels applied)

and treatment-1 (200 kg N ha<sup>-1</sup>). The genotype UAM-20 displayed a comparatively lower lint weight of 97.7 g, as presented in Figure 9. Although this genotype exhibited reduced lint weight in this block and treatment combination, it is essential to consider other factors that may have influenced these results, such as environmental conditions or genetic variability. Further investigation is required to assess the performance of UAM-20 under different circumstances and evaluate its overall suitability for cotton production.

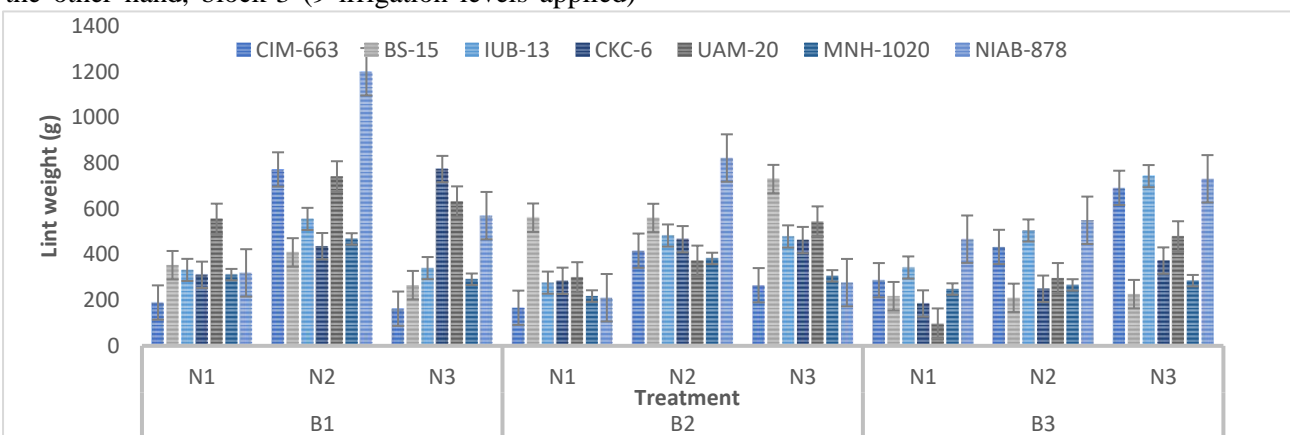


Figure 9. Effect of reduced irrigation levels and different N doses on lint weights of cotton. LSD All-Pairwise Comparisons Test of lint weight for Genotype \* Treatment \* block. B1= 18 Irrigation level, B2= 13 Irrigation level, B3= 9 Irrigation level.

**Water use efficiency (kg ha<sup>-1</sup> mm<sup>-1</sup>)**

The results of this study indicate highly significant with (p < 0.05) shown in Figure 10 differences in water use efficiency among the evaluated genotypes and treatments. Genotype NIAB-878 displayed the highest water use efficiency, with a 2.8 (kg ha<sup>-1</sup> mm<sup>-1</sup>) represented in Figure 10. This suggests that NIAB-878 optimizes water consumption, increasing productivity with minimal water input. Specifically, in Block-2 (13 irrigation applied) and treatment-3 (N doses 300 kg ha<sup>-1</sup>), NIAB-878 showed exceptional Water Use Efficiency. These findings highlight NIAB-878 as a promising genotype for regions grappling with water scarcity or prioritizing sustainable water management

practices. Conversely, genotype CIM-663 exhibited the lowest water use efficiency of 0.34 (kg ha<sup>-1</sup> mm<sup>-1</sup>) among the seven tested genotypes shown in Figure 10. In Block-3, with (9 irrigation levels applied), treatment-1 (N doses 200 kg ha<sup>-1</sup>) displayed significantly lower water use efficiency than the other genotypes. This implies that CIM-663 may need to be improved in effectively utilizing water resources for optimal growth and productivity. The observed lower water use efficiency underscores the potential unsuitability of CIM-663 for areas with limited water availability or where water conservation is a crucial concern.

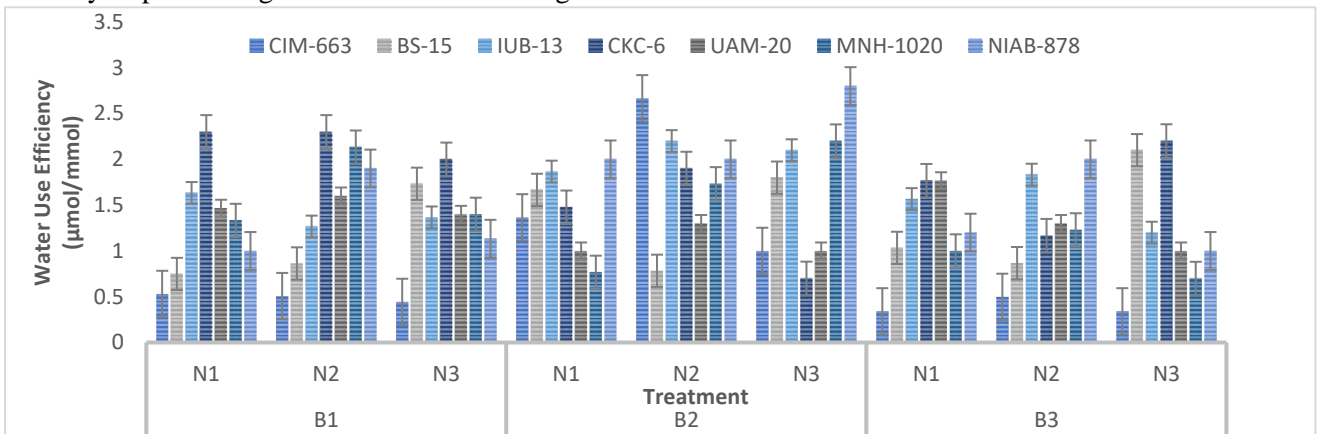


Figure 10. Effect of reduced irrigation levels and nitrogen different N doses on water use efficiency of cotton. LSD All-Pairwise Comparisons Test of water use efficiency for Genotype \* Treatment \* block. B1= 18 Irrigation level, B2= 13 Irrigation level, B3= 9 Irrigation level.

**Photosynthetic rate µmol CO<sub>2</sub>/ m<sup>2</sup> s<sup>-1</sup>**

The data relating to the photosynthetic rate of cotton is graphically presented in Figure 11. Genotype IUB-13 exhibited the highest photosynthetic rate, 62 µmol CO<sub>2</sub>/m<sup>2</sup> s<sup>-1</sup>, when grown in block-1 with (18 irrigation levels) and with treatment-2 (N dose 250 kg ha<sup>-1</sup>). This finding suggests that genotype IUB-13 is highly efficient in harnessing sunlight and converting it into chemical energy through photosynthesis. The statistical analysis's observed high significance further supports this result's robustness. In contrast, genotype MNH-1020 displayed the lowest photosynthetic rate among the genotypes tested. In Block-3, under the treatment conditions with an N level of 250 kg per ha<sup>-1</sup>, genotype MNH-1020 exhibited the lowest value of 36 µmol CO<sub>2</sub>/ m<sup>2</sup> s<sup>-1</sup> photosynthetic rate. This implies that MNH-1020 may have limitations in its photosynthetic efficiency, possibly affecting its overall growth and productivity. Further

investigations may be warranted to understand the underlying factors contributing to the reduced photosynthetic rate in genotype MNH-1020 and explore potential strategies to enhance its photosynthetic performance. The study's results reveal significant differences in photosynthetic rates among the seven evaluated cotton genotypes. This finding suggests that IUB-13 has the potential for high productivity due to its superior photosynthetic capabilities. The statistical significance of this result further reinforces its reliability. Conversely, genotype MNH-1020 exhibited the lowest photosynthetic rate among the genotypes tested. This implies that MNH-1020 may have limitations in its photosynthetic efficiency, which could affect its overall growth and productivity.

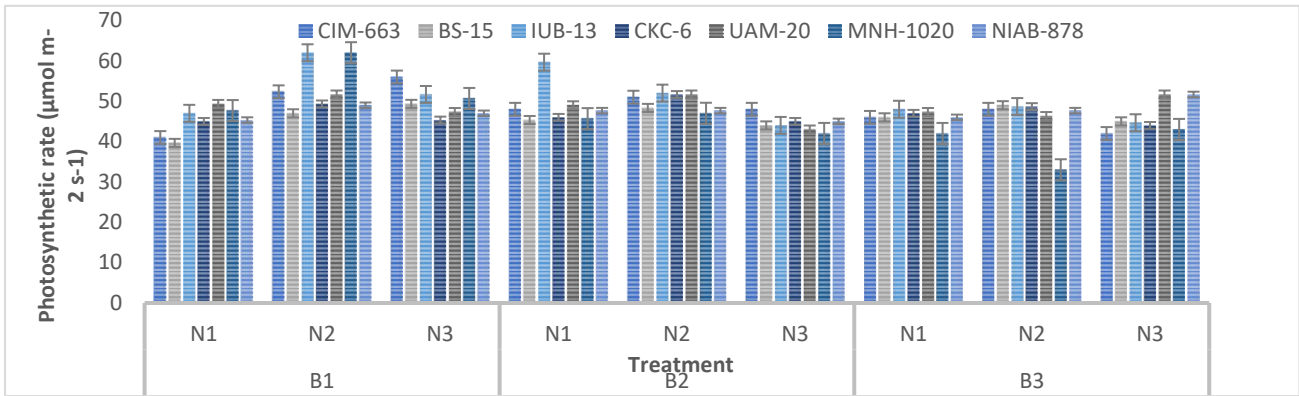


Figure 11. Effect of reduced irrigation levels and nitrogen different N doses on the photosynthetic rate of cotton. LSD All-Pairwise Comparisons Test of photosynthetic rate for Genotype \* Treatment \* block. B1= 18 Irrigation level, B2= 13 Irrigation level, B3= 9 Irrigation level.

**Transpiration rate (mmol H<sub>2</sub>O m<sup>-2</sup> s<sup>-1</sup>)**

The comprehensive study results indicate a statistically significant difference (p-value < 0.05) in the transpiration rate. Notably, the genotype CIM-663 demonstrated a substantially higher transpiration rate of 11.443 mmol H<sub>2</sub>O m<sup>-2</sup> s<sup>-1</sup> in block-1 (18 irrigation applied) and treatment-1 (N dose 200 kg ha<sup>-1</sup>), presented in Figure 12. This underscores the exceptional water uptake and transpiration efficiency of CIM-663, highlighting its remarkable ability to regulate and optimize water loss through the stomatal pores. Such efficient transpiration implies a heightened capacity of CIM-663 to maintain a favorable balance between water uptake and water transpiration, ultimately contributing to its robust growth and overall plant vigor. Conversely, the genotype CKC-6 exhibited a comparably lower transpiration rate of 6.333 mmol H<sub>2</sub>O m<sup>-2</sup> s<sup>-1</sup> in Block-3 (9 irrigation applied) and treatment-3 (300 Kg ha<sup>-1</sup>).

This discernible disparity in transpiration efficiency suggests the presence of certain limitations within CKC-6, potentially impacting its water utilization dynamics and overall plant performance. Exploring the underlying factors responsible for the observed variance in transpiration rates between CIM-663 and CKC-6 is crucial, as it can yield invaluable insights into the genetic, irrigation levels, and physiological mechanisms governing transpiration efficiency. The irrigation levels and N doses play an essential role in transpiration efficiency. By gaining a comprehensive understanding of these factors, researchers can devise targeted strategies to enhance the transpiration performance of CKC-6, thereby augmenting its resilience and productivity in water-limited conditions.

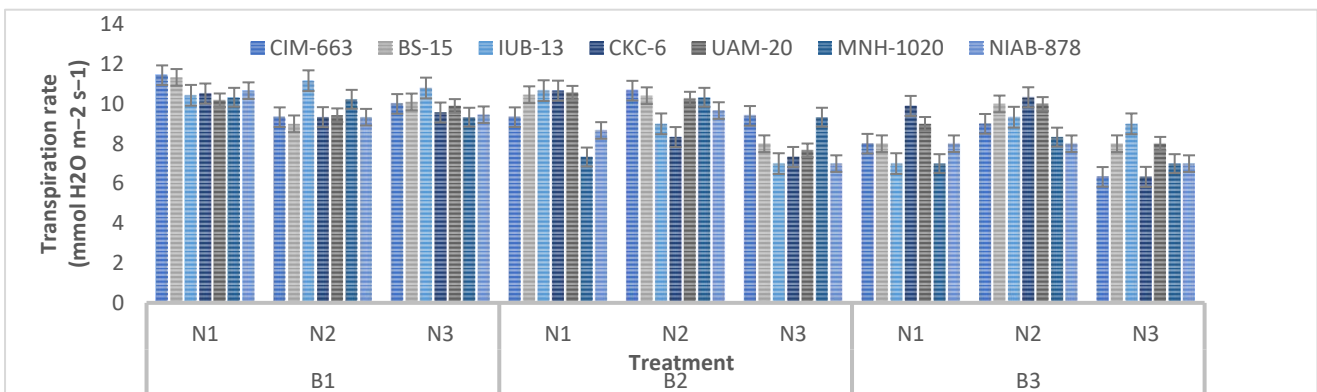


Figure 12. Effect of reduced irrigation levels and different N doses on the transpiration rate of cotton. LSD All-Pairwise Comparisons Test of transpiration rate for Treatment\*block\*genotype. B1= 18 Irrigation level, B2= 13 Irrigation level, B3= 9 Irrigation level

**Chlorophyll contents (µmol m<sup>-2</sup>)**

The analysis of the data produced meaningful findings, indicating significant distinctions among the genotypes that were examined. In block-1 (18

irrigation levels) and treatment-2 (250 Kg N ha<sup>-1</sup>), the genotype NIAB-878 exhibited the highest value of 48 µmol m<sup>-2</sup>, as shown in Figure 13. This finding indicates that NIAB-878 demonstrated superior

performance in the measured variable compared to the other genotypes in that specific block and treatment combination. The substantial increase in value associated with NIAB-878 suggests its potential for enhanced performance and productivity under similar conditions. Conversely, in block-3 (9 irrigation) and treatment-1 (200 Kg N ha<sup>-1</sup>), genotype BS-15 displayed the lowest value of 29 μmol m<sup>-2</sup>. This

indicates that BS-15 had a comparatively poorer performance in this block. It is essential to consider factors that may have influenced these results, such as N rate, irrigation level, environmental conditions, or genetic variability. Further investigations and evaluations are necessary to understand better the specific limitations or challenges faced by BS-15 in this context.

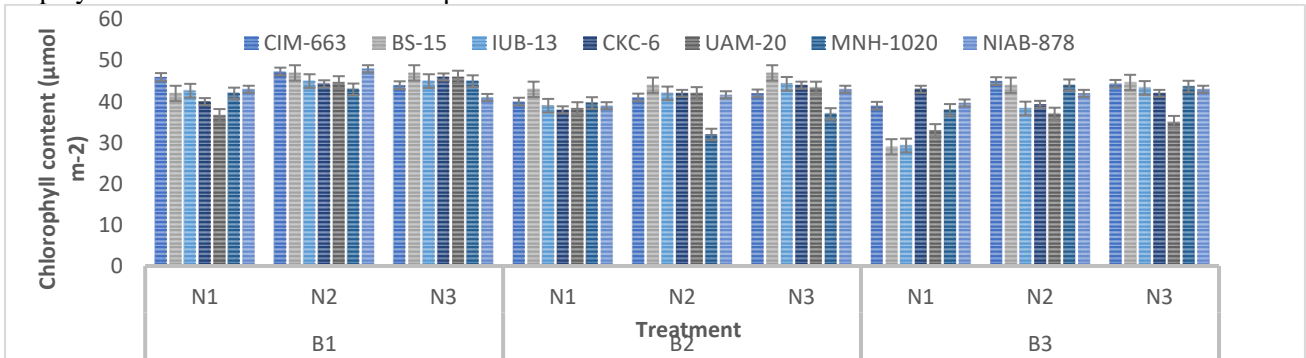


Figure 13. Effect of reduced irrigation levels and different N doses on chlorophyll contents of cotton. LSD All-Pairwise Comparisons Test of chlorophyll contents for Genotype \* Treatment\*block. B1= 18 Irrigation level, B2= 13 Irrigation level, B3= 9 Irrigation level.

**Nitrogen Use Efficiency and Phosphorus Analysis Nitrogen (%)**

The data on nitrogen levels reveals a significant difference (p-value < 0.05) among the seven genotypes tested. Genotype IUB-13 exhibited the highest nitrogen value of 0.84%, as shown in Figure 14, wherein block-1 (18 irrigation applied) and treatment-2 (250 kg ha<sup>-1</sup>). So, genotype IUB-13 can efficiently uptake and utilize nitrogen, potentially contributing to its superior growth and productivity. Conversely, CIM-663 displayed the lowest nitrogen value of 0.2167% in Block-3 (9 irrigation applied) and Treatment-1 (200 kg ha<sup>-1</sup>). This indicates that CIM-

663 may have limited nitrogen uptake and utilization, potentially hindering its overall growth and nutrient assimilation. Further investigations are warranted to understand the underlying factors contributing to the reduced nitrogen levels in CIM-663 and explore potential strategies to enhance its nitrogen utilization efficiency. Overall, the significant differences in nitrogen levels observed among the genotypes emphasize the importance of nitrogen management in plant growth and development. Optimizing nitrogen uptake and utilization can be vital in maximizing crop yield and improving agricultural sustainability.

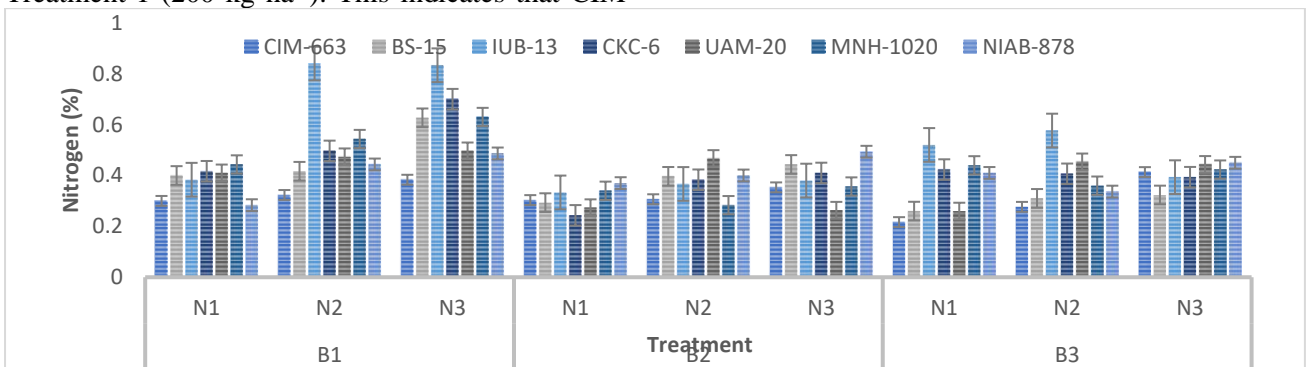


Figure 14. Effect of reduced irrigation levels and different N doses on N % cotton. LSD All-Pairwise Comparisons Test of N% for Genotype \* Treatment \* block. B1= 18 Irrigation level, B2= 13 Irrigation level, B3= 9 Irrigation level.

**Extractable potassium (ppm)**

The data analysis revealed that the results were statistically significant, with a p-value <0.05, as shown in Figure 15, indicating the observed differences in potassium values among the seven genotypes. Among the seven genotypes examined,

CIM-663 exhibited the highest potassium value of 172 ppm, as shown in Figure 15, specifically in block-2 (12 irrigation levels applied) and treatment-3 (300 kg N ha<sup>-1</sup> applied). The CIM-663 genotype, when subjected to this treatment, has a significant influence on potassium accumulation. On the other hand,

genotype CKC-6 displayed a lower potassium value of 52.33 ppm in block-3 (9 irrigation) and treatment-1 (200 kg N ha<sup>-1</sup>). This result implies that CKC-6 may

have lower potassium uptake or utilization efficiency under experimental conditions.

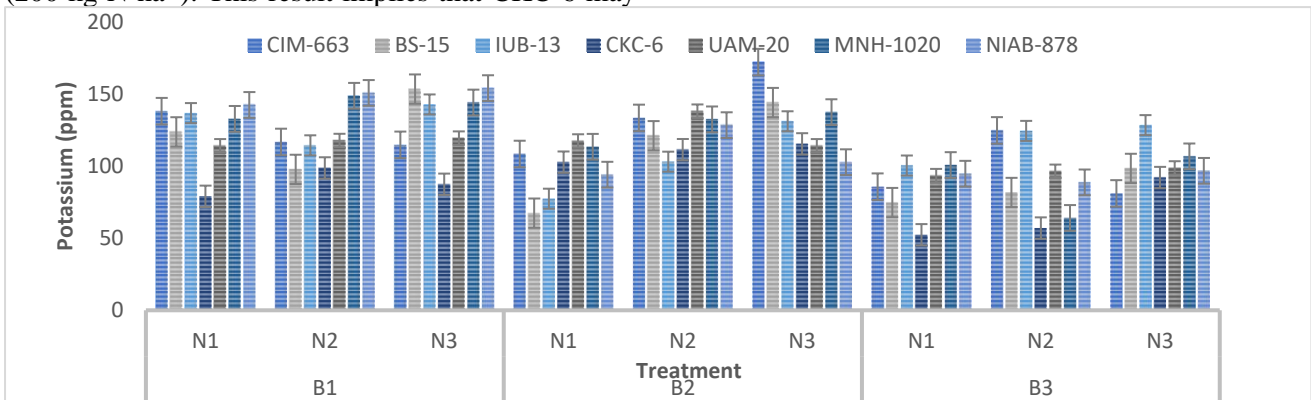


Figure 15. Effect of reduced irrigation levels and different N doses on the extractable potassium of cotton. LSD All-Pairwise Comparisons Test of k for Genotype \* Treatment \* block. B1= 18 Irrigation level, B2= 13 Irrigation level, B3= 9 Irrigation level.

**DISCUSSION**

The present study was conducted to investigate the impact of various N application rates as treatment (200 kg ha<sup>-1</sup>, 250 kg ha<sup>-1</sup>, and 300 kg ha<sup>-1</sup>) and DI on the response of different genotypes of the cotton crop. Various growth parameters such as plant height, number of bolls, number of squares, and number of monopodial branches were measured, along with yield and yield-contributing parameters at crop harvesting. Regarding plant height, genotype CKC-6 exhibited the highest average height among all seven genotypes. This observation was made in block-2 and treatment-2.2. However, it was observed that N practices did not significantly affect growth parameters. Similar results regarding yield components of cotton were reported by [16]. On the other hand, genotype CIM-663 had the lowest average height of 52.03 cm, observed in block-2 and treatment-1. This lowest genotype value may be due to less available N and genotype variation. These findings indicate that the choice of genotype and nitrogen treatment significantly influenced the plant height of cotton plants. When considering yield parameters, genotype NIAB-878 showed the highest average yield regarding the number of bolls, total lint weight, and bolls. This suggests that NIAB-878 may be a promising genotype for higher cotton yield. NIAB-878 shows the best performance in yield-related parameters, possibly due to the variation regarding up taking N. However, further analysis and comparison of other yield-contributing parameters would be necessary to fully evaluate this study's overall performance and the economic potential of different genotypes and N treatments. The data shows that genotype NIAB-878 had the highest water use efficiency (WUE) of 2.8 (kg ha<sup>-1</sup> mm<sup>-1</sup>) in block-2 and treatment-3, indicating optimal water consumption and increased productivity with minimal water input. In contrast, genotype CIM-663 exhibited the lowest

WUE of 0.34 (kg ha<sup>-1</sup> mm<sup>-1</sup>). This may be due to the importance of genotype selection for maximizing WUE in cotton crops. Similar finding by Liu et al., (2017) [17], WUE showed a slight increase with deficit irrigation. The data shows that genotype IUB-13 had the highest photosynthetic rate of 62 μmol CO<sub>2</sub>/ m<sup>2</sup> s<sup>-1</sup> in block-1 with 18 irrigation levels and treatment-2 with an N dose of 250 kg ha<sup>-1</sup>. In the same conditions, genotype NIAB-878 had a photosynthetic rate of 48 μmol m<sup>-2</sup>. This suggests that IUB-13 performed better photosynthesis than NIAB-878 in that specific block and treatment combination. The reason is that Irrigation water productivity increased with reduced irrigation water application in the study. A similar has been recorded by Guo et al., (2021) [18], whose results showed that N rate and irrigation levels were the main factors for transpiration and photosynthetic rate. The analysis of nutrient parameters revealed variations in N, phosphorus, and potassium content among the different genotypes and treatments. Genotype IUB-13 had the highest average N content, observed in block-1 and treatment-2. Because of N, supply increases could be attributed to the accumulation of excess external N beyond the plant's actual requirements, thereby limiting its ability to stimulate further growth. According to Iqbal et al. (2020) [19], a well-integrated nitrogen uptake and assimilation system may be the foundation for achieving high N in genotype IUB-1. At the same time, genotype CIM-663 had the lowest average N content, observed in block-3 and treatment-1. Among the genotypes, UAM-20 showed the highest moderate phosphorus content, observed in block-1 and treatment-3, while genotype CKC-6 had the lowest average phosphorus content, observed in block-2 and treatment-1. However, Iqbal et al., (2020) [19] reported that this effect may be attributed to various factors, such as variations in soil and climatic

conditions, as well as differences in the sensitivity of cotton cultivars to phosphorus levels. Regarding potassium, genotype CIM-663 exhibited the highest average potassium content, observed in block-2 and treatment-3. Due to the higher N rate in treatment 3, an intriguing consequence emerged as the availability of potassium experienced a significant boost, accentuating the profound impact of nutrient management on optimizing crop growth and productivity [20]. At the same time, genotype CKC-6 had the lowest average potassium content, observed in block-3 and treatment-1. With a decrease in N rate and irrigation level, potassium uptake reduces.

### CONCLUSION

The study concluded that genotype is vital in conserving fresh water and reducing N losses through many transformations. Deficit irrigation, particularly subsurface irrigation, plays a crucial role in addressing potential water scarcity, declining water resources, and the economic well-being of farmers; irrigation schemes and regions also lower the N from the leaching. It is significant for maintaining sustainable

water management practices, ensuring optimal water usage, and safeguarding regional and national incomes without compromising the reduction of the yield of cotton crops. The results of this study contribute to our knowledge of genotype-specific lint weight, highlighting the significance of selecting high-performing genotypes such as NAIB-878 for maximizing cotton productivity. Moreover, the practical implication of the study has direct relevance to cotton cultivation in Multan, as the study findings suggest potential improvements in irrigation strategies, crop management, and nutrient balance. Implanting our recommendations into the field can enhance the yield and sustainability of cotton farming in this region. Moreover, this research could be extended to assess the influence of other nutrients on the yield of cotton in connection with NUE and water deficit irrigation regimes. In addition, the long-term impact of deficit irrigation and NUE management on soil health including soil structure, microbial diversity and organic matter content could be addressed in future studies.

### ACKNOWLEDGMENTS

The authors are thankful to the MNS University of Agriculture Multan for providing lab facilities in the central lab of MNS University of Agriculture, Multan. The funding was provided by project [PSF-NSFC-IV/Agri/P-MNSUAM (30)] under the umbrella of Pakistan Science Foundation (PSF).

### AUTHOR'S CONTRIBUTION

Abid Hussain: Supervised the research  
Shoaib Ahmad and Junaid Imam: Conducted the research and analyzed the samples.  
Umair Riaz, Nabil Ikram, and Zulqernain Khan: Assisted in planning of the research  
Zia Ur Rahman Farooq, Adnan Fareed, Muhammad Awwab Tariq, Maher Iftikhar Ahmad: Contributed to the writing of this manuscript.

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