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Research Article

Evaluating Variation among Selected Cotton Genotypes for Growth, Yield and Boron-Use-Efficiency

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Abstract | Boron (B) plays significant roles in the growth, development, yield and quality of cotton. However, there exists a very narrow gap between plant deficiency and toxicity limits of B. We conducted this field study, following a thrice replicated randomized complete block split-plot design (main: B levels and sub: genotypes), to evaluate the growth, yield, and boron-use-efficiency of five cotton genotypes (Sohni, Chandi, Reshmi, Qalandri and CRIS-443) of Sindh under deficient (0 kg B ha^{-1}) and adequate (2.0 kg B ha^{-1}) levels of soil applied B (Borax, 11.5% B). The crop also received a blanket dose of 120-60-60 kg NPK ha^{-1}. The soil used was clay loam, alkaline in nature (pH: 8.2), slightly saline (EC: 1.7dS m^{-1}), while low in organic matter (0.79%) and diluted HCl-B (0.42 mg kg^{-1}). Both the sources of variance (B and cotton genotypes) (G) significantly ($p < 0.001$) affected all the traits. Cotton genotypes significantly differed for their B accumulation. Boron × genotypes interaction significantly ($p < 0.05$) affected the number of bolls and seed cotton yield. Qalandari produced maximum number of sympodia, bolls, seed cotton yield, and accumulated maximum B concentration under both the levels of B. Sohni had maximum ginning out turns and B accumulation under both the B levels. Reshmi produced maximum boll weight under both the B conditions. Qalandari appeared to be a potential genotype to perform both under low and high B input agriculture, being most efficient-responsive genotype. We concluded that the adequate B nutrition significantly affect most of the growth traits and seed yield of cotton genotypes, though independent of boron accumulation. Hence, a wide range of cotton genotypes may be involved to exploit their variation for B accumulation in quest of identifying B-use-efficient cotton genotypes.

Keywords: Cotton, Boron, Genotypic variation, Use-efficiency

Introduction

Boron (B) is a key micronutrient that is found deficient in crops and is believed to be responsible for cotton yield reduction in Pakistan (Shah et al., 2014, 2015; Rashid et al., 2022). It plays crucial roles in plant growth, development, and reproduction (Kohli et al., 2023). Cotton (*Gossypium hirsutum* L.) is one of the significant crops of Pakistan (Laghari et al., 2024). However, cotton yield is lower in Pakistan when compared to global average cotton production (GoP, 2024). Cotton requires B in adequate amounts and shows varying deficiency symptoms under B deficient conditions (Ahmed & Noaman, 2024). Cotton quickly responds to adequate B nutrition and need ~340 g B ha^{-1}, exporting 12% of plant accumulated B in its seed (Rochester, 2007). Soils with low organic matter and high calcareousness lead to nutritional disorders in cotton caused by B deficiency (Ahmed & Noaman, 2024). Boron is required by plants during all growth stages, with fruiting stage being more critical. However, its deficiency can lead to stunted growth and wilting and reddening of leaves. The B deficiency in Pakistan is reported to be spread over more than half of the agricultural land and is considered as the primary factor causing low cotton yields (Rashid et al., 2022).

Although soil B concentration ranges from 2.0 - 200 mg kg^{-1}, plant available B is only limited to 5 to 10% of that concentration (Diana, 2006). Hence, hundreds of crop species in >80 countries including Pakistan having calcareous soils suffer from B deficiency (Imtiaz et al., 2010). This B deficiency is reported for half of the cotton belt of Pakistan (Rashid et al., 2022).

The adequate plant available of 20 to 60 ppm is believed to be sufficient for cotton at its first square development to blooming stage (Rashid et al., 2022). Moreover, a dose of 2.6 kg B ha^{-1} is suggested to obtain optimum yield of cotton in Pakistan (Shah et al., 2014, 2015), while above this dose B toxicity may harm crops, since very narrow margin has been reported between the adequacy and toxicity of B (Shah et al., 2014, 2015; Rashid et al., 2022).

Nonetheless, genotypic variation has been reported among cotton varieties for their B requirement and use (Shah et al., 2014, 2015). Hence it is very imperative to evaluate the actual B requirements of various cotton varieties, and this was the primary motive of our conducting this field study aiming at evaluating the growth, yield and boron-use-efficiency of selected cotton genotypes of Sindh.

Materials and Methods

Place of research work: The field study was conducted at the research field of the Nuclear Institute of Agriculture (NIA) Tandojam, Sindh.

Detail of cotton genotypes: The experiment involved five cotton genotypes, viz. Reshmi, Qalandri, Sohni, Chandi, and CRISS-342. The pure seeds of these five cotton genotypes were obtained from the concerned cotton breeders, representing major cotton research Institutes of Sindh.

Experimental detail: A field experiment was conducted in a two-factor randomized complete block split plot design (RCBD) with three repeats. Factor A comprised of five cotton genotypes, i.e., Reshmi, Qalandri, Sohni, Chandi, and CRISS-342 (Subplot) while factor B included two application doses of B, i.e., 0 kg ha^{-1} (Control) and 2.0 kg B ha^{-1}.

Fertilizer application: The requisite doses of B were maintained through soil application of Borax (11.5% B). The crop also received recommended doses of nitrogen (120 kg ha^{-1}), phosphorus (60 kg ha^{-1}) and potassium (60 kg ha^{-1}) through urea, single super phosphate, and potassium sulphate, respectively. All the phosphorus, potassium and boron along with one third dose of the nitrogen, was broadcasted to the soil at sowing time. The remaining doses of nitrogen were applied to the crop at the time of first irrigation and flowering stage of cotton crop in spilt.

Soil analyses: Soil samples were collected from the experimental field at the depth of 0-20 cm prior to cotton sowing. The collected soil samples were brought into the laboratory and processed for the analysis of various soil properties, including texture, electrical conductivity (EC), pH, organic matter, and diluted HCl-B following standard methods (Ryan et al., 2001).

Decontamination of cotton seed: To prevent fungal infection, the seeds were surface sterilized for five minutes using a 5% sodium hypochlorite solution.

Sowing and harvesting: The sowing was done using 50 g fuzzy seeds per experimental unit of 14.5 m^2, by making 2.0 cm deep hole. Each experimental unit consisted of six 5.0 m long lines of each genotype (three furrows both sides planted; furrow width 1.5 ft and bed width 2.5 ft.). Afterwards, the plants were allowed to grow to maturity, and three pickings were obtained.

Growth and yield parameter: At maturity, the plants were harvested to record different growth and yield parameters of cotton, viz. number of sympodia per plant, number of bolls per plant and seed cotton yield (g per plant).

Plant sampling, processing and analysis: Plant B concentration was determined by dry ashing and subsequently measured by Colorimetry using Azomethane-H (Ryan et al., 2001).

Statistical analyses: The data were subjected to analysis of variance (ANOVA) using Statistix ver. 8.1. The significant differences among treatments were compared using Tukey's honestly significant difference test at alpha 0.05 ($P \leq 0.05$).

Results

Number of sympodia: The number of sympodia varied significantly among genotypes ($p<0.001$), but boron application itself did not have a statistically significant effect. The highest number of sympodia was observed in Qalandari (34.7), followed by Sohni (30.8), while CRIS-342 had the lowest mean sympodia (21.8). Though boron application increased the mean number of sympodia from 26.1 (deficient) to 28.0 (adequate), this increase was not statistically significant. Genotypic variation was evident, with Qalandari showing the greatest response, while Reshmi and CRIS-342 had lower sympodial development under boron stress.

Number of bolls: Boron application significantly increased the number of bolls ($p<0.001$), with genotypes also differing significantly ($p <0.001$). The mean number of bolls increased from 58.9 (deficient) to 69.8 (adequate) across genotypes, showing boron's positive role in boll retention and development. Qalandari and CRIS-342 had the highest boll counts (90.4 and 79.7, respectively), while Reshmi had the lowest (34.8). The interaction effect of boron and genotype was also significant ($p<0.001$), indicating that genotypes responded differently to boron levels. The most substantial increase in boll number due to boron application was seen in CRIS-342 (66.3 → 93.0), whereas Reshmi and Chandi showed minimal improvement.

Table 1. Number of sympodia and bolls of selected cotton genotypes at deficient and adequate boron levels

Genotype	Number of sympodia			Number of bolls		
	0 kg B ha^{-1}	2.0 kg B ha^{-1}	Genotype- Mean	0 kg B ha^{-1}	2.0 kg B ha^{-1}	Genotype- Mean
Reshmi	19.2	25.8	22.5B	32.7g	36.8g	34.8B
Qalandari	32.3	37.0	34.7A	86.0b	94.8a	90.4A
Sohni	30.0	31.5	30.8AB	53.3f	64.0cd	58.7AB
Chandi	25.0	26.3	25.7B	56.2ef	60.2de	58.2AB
CRIS-342	24.2	19.3	21.8B	66.3c	93.0a	79.7A
B-Mean	26.1	28.0		58.9B	69.8A	

Table 2. Boll weight and seed cotton yield of selected cotton genotypes at deficient and adequate boron levels

Genotype	Boll weight (g)			Seed cotton yield (g $plant^{-1}$)		
	0 kg B ha^{-1}	2.0 kg B ha^{-1}	Genotype- Mean	0 kg B ha^{-1}	2.0 kg B ha^{-1}	Genotype- Mean
Reshmi	3.1	3.4	3.25A	104.3f	112.4ef	108.4D
Qalandari	2.2	2.4	2.32C	188.5b	215.0a	201.7A
Sohni	2.2	2.4	2.29C	126.2de	138.5cd	132.3C
Chandi	2.6	2.7	2.65B	125.1de	140.9cd	133.0C
CRIS-342	2.3	2.4	2.36C	149.8c	203.1ab	176.4B
B-Mean	2.50B	2.65A		138.8B	162.0A	

Table 3. Ginning-out-turn (GOT) and boron accumulation of cotton genotypes at deficient and adequate boron levels

Genotype	GOT (%)			Boron accumulation (%)		
	0 kg B ha^{-1}	2.0 kg B ha^{-1}	Genotype- Mean	0 kg B ha^{-1}	2.0 kg B ha^{-1}	Genotype- Mean
Reshmi	37.1	39.4	38.3B	68.5	73.3	70.9AB
Qalandari	35.2	40.1	37.7B	70.6	86.6	79.0A
Sohni	43.2	44.2	43.7A	66.1	80.4	73.2A
Chandi	38.3	40.1	39.2B	51.5	62.6	57.1C
CRIS-342	33.7	38.7	36.2B	60.9	65.8	63.4BC
B-Mean	37.5B	40.5A		63.5B	73.7A	

Boll weight: Boron application had a significant effect on boll weight ($p<0.01$), and genotypic differences were highly significant ($p<0.001$). The interaction between boron and genotype (B × G) was not significant, indicating that all genotypes showed a similar trend in response to boron application. The overall mean boll weight increased from 2.50 g (deficient) to 2.65 g (adequate), suggesting that boron positively influenced boll development. Reshmi had the highest boll weight (3.25 g), followed by Chandi (2.65 g), while Qalandari had the lowest (2.32 g), despite being the highest-yielding genotype. The relatively smaller increase in boll weight compared to other yield parameters suggests that B contributes more to boll retention than to individual boll enlargement.

Seed cotton yield: Boron application significantly increased seed cotton yield ($p<0.001$), with genotypic differences being highly significant ($p<0.001$). The highly significant interaction effect ($p<0.001$) indicates that genotypes responded differently to boron fertilization. The overall mean seed cotton yield increased from 138.8 g $plant^{-1}$ (deficient) to 162.0 g $plant^{-1}$ (adequate), highlighting boron's positive effect on productivity. Qalandari recorded the highest yield (201.7 g $plant^{-1}$), followed by CRIS-342 (176.4 g $plant^{-1}$), whereas Reshmi had the lowest yield (108.4 g $plant^{-1}$). The highest increase in seed cotton yield due to boron application was observed in CRIS-342 (149.8 → 203.1 g $plant^{-1}$), showing its strong response to boron fertilization.

Ginning-out-turn (GOT) (%): Boron application significantly increased GOT ($p<0.001$), indicating that boron positively influences fiber recovery from seed cotton. Genotypic differences were also significant ($p<0.001$), meaning that different genotypes varied in their intrinsic GOT potential. The overall mean GOT increased from 37.5% (boron deficient) to 40.5% (boron adequate), showing an improvement in fiber yield due to boron. Among genotypes, Sohni exhibited the highest GOT (43.7%), followed by Chandi (39.2%) and Reshmi (38.3%). CRIS-342 had the lowest GOT (36.2%), but it still showed improvement with boron application. The B

× G interaction was non-significant, indicating that while boron improved GOT, the relative ranking of genotypes remained unchanged.

Boron accumulation (%): Boron accumulation significantly increased with boron application ($p<0.001$), confirming that boron fertilization enhances uptake and storage in plant tissues. Genotypic differences were also significant ($p<0.001$), meaning different cotton genotypes have varying capacities to absorb and utilize boron. The overall mean boron accumulation increased from 63.5% (deficient) to 73.7% (adequate), indicating improved boron uptake when sufficient boron was available. Qalandari exhibited the highest boron accumulation (79.0%), followed closely by Sohni (73.2%), while Chandi had the lowest accumulation (57.1%). Like GOT, the B × G interaction was non-significant, indicating that the effect of boron was consistent across genotypes.

Discussion

Boron (B) is a key micronutrient essential for plant growth and development, and its deficiency is a major limiting factor in cotton production, particularly in Pakistan (Marschner, 2011; Rashid et al., 2022). Cotton is highly sensitive to boron deficiency, which adversely affects its growth, reproductive development, and yield (Azeem et al., 2021).

In Pakistan, boron deficiency is reported as a primary contributor to lower cotton yields, leading to issues such as stunted growth, wilting, and cotton leaf reddening (Shah et al., 2015; Rashid et al., 2022). Given these challenges, evaluating the boron requirements of different cotton genotypes is crucial to improving productivity.

Boron deficiency significantly reduced seed cotton yield and its associated traits, including boron uptake and boron use efficiency, across all cotton genotypes, though the extent of reduction varied (Shah et al., 2015). This disparity in yield attributes, boron uptake, and boron-use-efficiency among genotypes highlights differences in adaptation to varying boron levels, emphasizing the importance of adequate boron nutrition for optimal cotton growth (Mehran et al., 2023).

Earlier, it has been reported that the enhanced biomass production of cotton is directly related with the increased nutrient uptake and use efficiency (Zia-ul-hassan & Arshad, 2008a) and is linked with leaf area and root biomass (Zia-ul-hassan & Arshad, 2008b; Zia-ul-hassan & Arshad, 2010; Zia-ul-hassan & Arshad, 2011), in case of potassium.

Boron plays a crucial role in physiological, biochemical, and metabolic processes, including enzymatic activities in plants (Long & Peng, 2023). Its deficiency can lead to significant decreases in growth, yield, and yield contributing parameters of cotton (Ahmad et al., 2019).

Consistent with these findings, our study demonstrated that boron deficiency led to a reduction in the number of sympodia per plant, bolls per plant, and boll weight, ultimately impacting the overall yield of different cotton genotypes.

Genotypic differences in boron-use-efficiency have been well-documented (Fontes et al., 2008; Shah et al., 2015). Boron-efficient cotton genotypes accumulate more boron in their floral parts compared to boron-inefficient genotypes (Jian et al., 2004).

This study also observed significant genotypic variation, where Qalandari and CRIS-342 exhibited the highest boll count and seed cotton yield, whereas Reshmi displayed the lowest performance under boron deficiency. Such variations suggest that specific genotypes possess a greater ability to utilize boron efficiently for reproductive growth and yield formation. Similarly, Bogiani and Rosolem (2012) highlighted genotypic differences among cotton cultivars concerning the onset and severity of boron deficiency symptoms.

In regions with calcareous soils, such as Pakistan, boron deficiency is a widespread problem affecting nearly half of the cotton belt. The adequate plant-available boron concentration for cotton ranges from 20 to 60 ppm at the first square development to blooming stage (Rashid et al., 2022).

Furthermore, due to severe deficiency of B in Pakistani soils, the optimal dose of 2.6 kg ha^{-1} is suggested to achieve enhanced cotton yields in Pakistan (Shah et al., 2014, 2015). However, due to the narrow margin between boron adequacy and toxicity, excessive boron application can negatively affect plant growth (Rashid et al., 2022).

The variation in genotypic responses to boron observed in this study underscores the necessity of determining precise boron requirements for different cotton genotypes (Shah et al., 2015). Earlier, Zia-ul-hassan et al. (2014) reported significant variations among cotton genotypes for their potassium use efficiency.

The response of cotton genotypes to boron fertilization in our study aligns with previous research on other crops. The genotypic variation among different canola varieties were observed in relation to different B levels (Tabatabaei & Noori, 2014).

In our findings, the interaction between boron and genotype was significant for seed cotton yield, indicating differential responses of genotypes to boron fertilization. Notably, CRIS-342 showed the most substantial increase in yield upon boron application, suggesting its higher sensitivity to boron deficiency and stronger response to fertilization.

Moreover, our study revealed that boron application improved ginning-out-turn (GOT) and boron accumulation in cotton genotypes. The increased GOT values under adequate boron conditions indicate enhanced fiber recovery, a trend that was consistent across genotypes.

In addition to above, boron accumulation varied significantly among genotypes, with Qalandari and Sohni exhibiting the highest uptake, while Chandi had the lowest. These findings support the notion that different genotypes have distinct capacities for boron absorption and utilization.

Conclusion

In summary, this study confirms that boron deficiency negatively affects cotton growth, boll retention, and seed cotton yield, with genotypic variation playing a critical role in determining boron-use-efficiency. The observed responses underscore the importance of selecting boron-efficient genotypes for improved productivity in boron-deficient soils. Future research should focus on involving a wide range of cotton genotypes to exploit their variation for B accumulation in quest of identifying B-use-efficient cotton genotypes.

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Author Contribution

SAM: Field study, data collection, chemical analysis; JAS: Supervision, manuscript writeup; SS & NR: Help in data collection; RV & VS: Data analysis, format and style. All authors approved and assumed the responsibility of the content of MS.

Conflict of Interest

No competing interests are disclosed by the authors.

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