Pak. J. Bot., 47(5): 1657-1663, 2015.

RESPONSE OF COTTON GENOTYPES TO BORON UNDER B-DEFICIENT AND B-ADEQUATE CONDITIONS

JAVAID AHMED SHAH[1*], ZIA-UL-HASSAN[2], INAYATULLAH RAJPAR[2] AND MAHBOOB ALI SIAL[1]

[1]*Nuclear Institute of Agriculture (NIA) Tandojam*
[2]*Department of Soil Science, Sindh Agriculture University, Tandojam*
**Corresponding author's e-mail: jashah76@yahoo.com*

Abstract

Balanced boron (B) application is well-known to enhance the cotton production; however, the narrow range between B-deficiency and toxicity levels makes it difficult to manage. Cotton genotypes extensively differ in their response to B requirements. The adequate dose of B for one genotype may be insufficient or even toxic to other genotype. The effects of boron (B) on seed cotton yield and its various yield associated traits were studied on 10 cotton genotypes of Pakistan. The pot studies were undertaken to categorize cotton genotypes using B-deficient (control) and B-adequate (2.0 kg B ha^{-1}) levels arranged in CRD with four repeats. The results indicated that the seed cotton yield, yield attributes and B-uptake of genotypes were comparatively decreased in B-deficient stressed treatment. Genotype NIA-Ufaq exhibited wide range of adaptation and ranked as "efficient-responsive", as it produced higher seed cotton yield under both B-regimes. SAU-2 and CIM-506 were "highly-efficient" and remaining all genotypes were "medium-efficient". Genotype Sindh-1 produced low seed cotton yield under B deficient condition and ranked as "low-efficient". B-efficient cotton genotypes can be grown in B deficient soils without B application.

Key words: B-uptake, B-use efficiency, *Gossypium hirsutum* L., genotypic variation, Ranking methods.

Introduction

Balanced boron (B) application enhanced the cotton production, as B is involved in various metabolic functions of plant, like sugar transport and plant respiration; formation of meristematic tissues and flowers and seed production (Camacho-Cristol *et al.,* 2008). B-deficiency is wide spread in many cotton growing areas of world including Pakistan (Rosolem *et al.,* 2001), which significantly restricted the seed cotton yield (De Oliveir *et al.,* 2006). In Pakistan, about 50% of soils, under cotton cultivation are deficient in B (Rashid, 2006). Relatively, B deficiency is difficult to manage due its narrow range between sufficient and toxic levels (Miwa *et al.,* 2007). The continuous application of B without knowing the soil conditions can also create the toxicity problem (Mengel & Kirkby 2001). This problem became more serious, when wide variation in B requirement of crop genotypes and species was exposed (Rerkasem *et al.,* 1993). Cotton genotypes extensively vary in their response to B. Hence, its slight over application can be risky, due to its possible toxic effects (Rashid, 2006).

Comparatively, B-efficient genotypes utilize B more efficiently from B deficient medium, thus can be successfully grown in B deficient soil without any additional B application. Inversely, B-responsive genotypes require additional B application to produce the maximum yield (Rengel & Damon, 2008). Hence, growing of B-efficient and in-efficient cotton genotypes accordingly not only overcomes B deficiency problem but also reduce the input cost of fertilizer (Baligar *et al.*, 2001; Arain *et al.,* 2008). In cotton, B-inefficient genotypes relatively accrued less B in vegetative and floral organs than the efficient ones (Fontes *et al.,* 2008).

A wide range of genotypic variation in relation to B-use-efficiency has been found in numerous cotton cultivars (Fontes *et al.,* 2008). The time of start and magnitude of B-deficiency symptoms differed among cotton genotypes (Bogiani & Rosolem, 2012). Brazilian cotton genotype ITA 90 is reported to be more sensitive to B-deficiency than cv. Fibermax 966 (Zancanaro & Tessaro, 2006). Later on (Zia-ul-Hassan *et al*., 2011) ranked cotton genotype NIBGE-2 "efficient-responsive", CIM-506 as "non-efficient" and Desi okra as "non-responsive" genotypes under potassium deficiency and adequacy stresses. Recently, extensive dissimilarity has observed in potassium-use-efficiency of some Bt and non-Bt cotton genotypes of Pakistan (Zia-ul-Hassan *et al*., 2014). Moreover, Milka *et al*. (2013) found significant variation among 40 wheat genotypes to boron deficiency and toxicity tolerance. Very limited international literature is available on B use efficiency of cotton genotypes. However, no any national research on B-use-efficiency of cotton genotypes is carried out. Therefore, ten popular cotton genotypes, collected from all leading cotton breeding Institutes of Pakistan were selected for this study. The present pot study was categorize 10 promising cotton (*Gossypium hirsutum* L.) genotypes of Pakistan on the basis of their B-use-efficiency and seed cotton yield by adopting a method of ranking as reported by Gill *et al*. (2004). This method of ranking is frequently used for ranking of crop genotypes. Gill's method classifies the crop genotypes into 3 groups like low, medium and high efficient or responsive.

Materials and Methods

A pot study was undertaken in wire-house at Experimental Farm of Nuclear Institute of Agriculture, Tandojam [N25^{0}25'17.6556"/E68^{0}32'30.21"], Sindh, Pakistan during cotton growing season 2013. The objectives of the study were to categorize 10 selected cotton genotypes of Pakistan under B-deficient and B-adequate regimes. The treatments i.e., B-deficient as control and B-adequate (2.0 kg B ha^{-1}); and cotton genotypes (IR-NIBGE-1524, MNH-886, CIM-506, SAU-2, Sindh-1, Chandi, NIA Ufaq, NIAB-78, NIAB-777 and CRIS-342) were arranged in completely randomized design (CRD) with four repeats. Boron deficiency (< 0.5 mg B kg^{-1} of soil) in pots was maintained by using B deficient soil, while B-adequacy by the application of 0.133g Borax (11.3% B) per pot. Four healthy seeds of each cotton genotype were planted at equal space in plastic pot, lined with polythene sheet and filled with 15 kg processed soil. The soils used in experiment was slightly alkaline in reaction (pH 8.2), non-saline (ECe 1.9 dS m^{-1}), highly calcareous ($CaCO_3$ 13.2%) in nature and clay loam in texture. It was deficient in organic matter (0.77%), Kjeldahl nitrogen (0.064%), $NaHCO_3$-extractable phosphorus (7.2 mg kg^{-1}) and diluted HCl boron (0.42 mg kg^{-1}), but adequate in NH_4OAc-extractable potassium (203 mg kg^{-1}). The recommended dose of nitrogen (200 kg ha^{-1}), phosphorus (100 kg ha^{-1}) and potash (70 kg ha^{-1}) was applied as urea (46% N), single super phosphate (18% P_2O_5) and sulphate of potash (50% K_2O). All phosphorus, potassium, boron and 1/3 of nitrogen were applied as basal dose. The remaining nitrogen was divided into two equal parts and applied during two growth stages viz., at flowering and boll formation stages. Three seedlings from each pot were harvested after five weeks of emergence and one plant was allowed to grow up till maturity. The harvested plants were washed with deionized water, dried in oven at 70°C till constant weight, grounded and passed through 2 mm sieve. Then, one g of thoroughly mixed material was used for the B analysis (Ponnamperuma *et al.,* 1981). The remaining one plant in each pot was harvested after recording the agronomic observations like sympodia per plant, bolls per plant, boll weight, seed cotton yield per plant. The relationships of B were computed through the subsequent formulae:

- B uptake = Seed cotton yield × B concentration (Nawaz *et al.*, 2006; Zhang *et al.*, 2007)
- B-use-efficiency = Seed cotton yield ÷ B concentration (Siddiqui & Glass, 1981)
- B-efficiency-ratio = [(Value at deficient B ÷ Value at adequate B) × 100] (Gunes *et al.,* 2006)

Finally, the ranking of cotton genotypes was performed by using a method as described by Gill *et al*. (2004). In this method, cotton genotypes were ranked by using index scoring techniques. If $x > \mu + STD$, the genotype was ranked as high and if $x < \mu - STD$ the genotype was categorized as low, while, medium for remaining values, where x stands for the genotype mean for certain parameter, μ represents the population mean of that parameter and STD is the standard deviation of population mean. Formerly, the genotype means were categorized into three different classes i.e. low, medium and high by allocating index scores of 1, 2, and 3, respectively. Finally, Metroglyph diagrams were developed with Microsoft Excel (Microsoft Corp, Redmond, WA, USA) using the index scoring ranges.

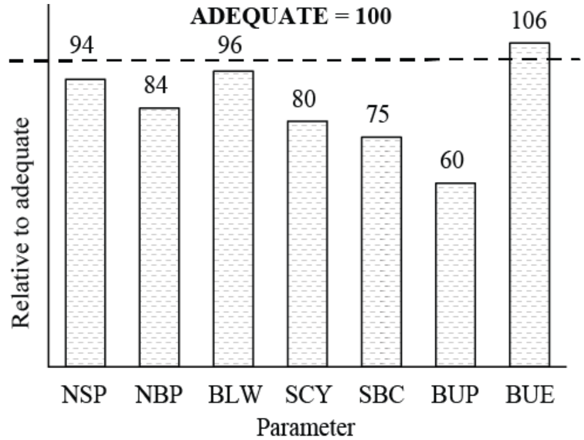

Fig. 1. Performance of cotton genotypes at deficient relative to adequate level of B in pot study (NSP, NBP, BLW and SCY are number of sympodia per plant, number of bolls per plant, boll weight (g) and seed cotton yield (g), respectively). SBC: shoot B concentration (μg g^{-1}); BUP: boron uptake (mg SCY^{-1}); BUE: B use efficiency (g^2 SCY mg^{-1} B uptake).

Results

The results indicated that the seed cotton yield and yield attributed of all cotton genotypes were affected with B-levels. The categorization of cotton genotypes in different classes (low, medium and high) reflects the wide genotypic variation for their response to B levels (Table 1). Cotton genotypes showed extensively difference in the mean values of production of sympodia per plant, bolls per plant, boll weight and seed cotton yield at both B regimes. Sympodia per plant of cotton genotypes varied from 4.5 for Sindh-1 to 8.2 for NIA-Ufaq, with an average of 5.9 at B deficient level. At adequate B level, it ranged from 5.3 for Sindh-1 to 8.3 for NIA-Ufaq, with a mean of 6.3 (Table 1). The comparative value for sympodia per plant at B deficient level was 94, showing 6% decrease to adequate B level, i.e. 100 (Fig. 1). Mostly, B-efficiency-ratio of all the genotypes was > 80. The minimum B efficiency ratio of 81 was recorded for SAU-2 and CRIS-342 (Table 1). Similarly, Bolls per plant extended from 10.2 for Sindh-1 to 21.2 for NIA-Ufaq, with a mean of 14.0 at B deficient regime. It varied from 11.8 for Sindh-1 to 23.8 for NIA-Ufaq with average of 16.6 at B adequate condition (Table 1). At B deficiency stress, number of bolls per plant reduced by 16% as compared to adequate level of B (Fig. 1). B-efficiency-ratio of three genotypes was <80. However, seven genotypes maintained B-efficiency-ratio > 80 in order of NIA-Ufaq, NIAB-78 and CRIS-342 > SAU-2 and Sindh-1 > CIM-506 > MNH-886 (Table 1). Moreover, bolls weight (g) of cotton genotypes varied from 2.0 for Sindh-1 and Chandi to 3.4 for SAU-2, with an average of 2.6 at B deficient level. At B adequate level, it ranged from 2.3 for Sindh-1 and NIAB-78 to 3.5 for MNH-886, with a mean of 2.7 (Table 1). Relatively, B deficiency reduced the boll weight of genotypes by 4% as compared adequate level of B (Fig. 1). All the genotypes attended

B-efficiency-ratio > 80 except Chandi, which attended 72. The order of B efficiency ratio was NIAB-78 > SIM-506, IR-NIBGE-1524 and SAU-2 > NIA-Ufaq > CRIS-342 > NIAB-777 and MNH-886 > Sindh-1 (Table 1). Seed cotton yield (g) of cotton genotypes ranged from 20.8 for Sindh-1 to 60.7 for NIA-Ufaq, with a mean of 36.4 under B deficiency stress. At adequate B, it varies from 27.4 for Sindh-1 to 68.6 for NIA-Ufaq, with an average of 45.5 (Table 2). Boron deficiency reduced seed cotton yield by 20% compared to adequate level of B (Fig. 1). Half of the genotypes accrued < 80 B-efficiency-ratio. The minimum B-efficiency-ratio was noted in Chandi. The remaining half of the genotypes retained > 80 B-efficiency ratio in sequence of NIAB-78 > NIA-Ufaq and SAU-2 > SIM-506 and CRIS-342 (Table 2).

Diverse response of cotton genotypes was observed under both B levels. Boron rates affected shoot B concentration, B uptake and B-use-efficiency. Shoot B concentration (μg g^{-1}) of cotton genotypes fluctuated from 60.7 for NIAB-777 to 86.4 for NIAB-78, with a mean of 72.4 at B deficiency stress. However, under adequate B conditions, it varied from 72.4 for NIA-Ufaq to 113.8 for Chandi, with a mean of 96.8 (Table 2). Shoot B concentration reduced by 25% under B deficiency stress as compared to adequate level of B (Fig. 1). Five cotton genotypes occurred < 80 B efficiency ratio, of which minimum was recorded in NIAB-777. The rest of five genotypes maintained > 80 B-efficiency-ratio in order of NIA-Ufaq > MNH-886 > NIAB-78 > Sindh-1 and CRIS-342(Table 2). Boron uptake (μg seed cotton $yield^{-1}$) of cotton genotypes varied from 1678 for Sindh-1 to 4296 for NIA-Ufaq, with an average of 2586 at B deficient level. At B adequate level, it ranged from 2756 for Sindh-1 to 5560 for SAU-2, with a mean of 4326 (Table 3). Boron deficiency reduced B uptake by 40% than the B adequate conditions (Fig. 1). Only one genotype NIA-Ufaq retained > 80 B-efficiency-ratio. All other genotypes attained < 80 B-efficiency ratio. Cotton genotype NIAB-777 maintained least B-efficiency-ratio (Table 3). Moreover, B-use-efficiency (g^2 seed cotton yield mg^{-1}seed cotton uptake) of cotton genotypes at deficient B level ranged from 0.258 for Sindh-1 to 0.858 for NIA-Ufaq, with a mean of 0.517. At adequate level it varied from 0.272 for Sindh-1 to 0.947 for NIA-Ufaq, with a mean of 0.490 (Table 3). The relative value for B-use-efficiency (106) showed that cotton genotypes more efficiently utilized B, under B deficient stress (Fig. 1). Six cotton genotypes attained > 100 B-efficiency-ratio in order of CIM-506 > SAU-2 > NIAB-777 > NIAB-78 > CRIS-342 > IR-NIBGE-1524. The minimum B-efficiency-ratio was noted in MNH-886 (Table 3).

Moreover, the correlation analysis revealed that seed cotton yield had highly significant ($p<0.01$) relationship with bolls per plant, B uptake and B-use-efficiency; and non-significant with shoot B content at both B levels. However, seed cotton yield was significant ($p<0.05$) correlated with boll weight at B deficient level and non-significantly at B adequate level (Table 5).

Cotton genotypes were ranked at both B regimes (Gill *et al.*, 2004). Cotton genotype Sindh-1 was ranked as "low-efficient"; CIM-505, SAU-2 and NIA-Ufaq as "high-efficient"; and remaining other genotypes as "medium-efficient" at B deficient level (Fig. 2; Table 4). Moreover, at adequate B level Sindh-1 and NIAB-78 were found as "low responsive"; NIA-Ufaq as "high responsive"; and left over genotypes as "medium responsive" (Fig. 3; Table 4).

Table 1. Sympodia per plant, bolls per plant and boll weight (g) of 10 cotton genotypes under deficient and adequate B in soil (Def. B, Adq. B and BER are deficient B, adequate B and B-efficiency-ratio, respectively). Values in bold following a genotype mean within each column are index scores (see Materials and Methods). Genotype means followed by similar index scores in a column are like in performance.

Genotype	Sympodia $plant^{-1}$					Bolls $plant^{-1}$					Boll weight (g)				
	Def. B	IS	Adq. B	IS	BER	Def. B	IS	Adq. B	IS	BER	Def. B	IS	Adq. B	IS	BER
IR-NIBGE-1524	5.2	2	5.3	2	98	12.3	2	15.7	2	79	2.4	2	2.4	2	101
MNH-886	5.9	2	5.9	2	99	10.5	2	13.0	2	81	3.2	3	3.5	3	90
CIM-506	7.1	3	7.2	2	99	19.2	3	22.2	3	86	2.5	2	2.5	2	101
SAU-2	4.9	2	6.0	2	81	15.2	2	17.5	2	87	3.4	3	3.4	3	101
Sindh-1	4.5	1	5.3	2	85	10.2	1	11.7	1	87	2.0	1	2.3	2	88
Chandi	7.2	3	7.3	3	98	13.2	2	17.3	2	76	2.0	1	2.8	2	72
NIA Ufaq	8.2	3	8.3	3	99	21.2	3	23.8	3	89	2.9	2	2.9	2	99
NIAB-78	5.2	2	5.7	2	92	12.2	2	13.7	2	89	2.3	2	2.3	1	103
NIAB-777	5.5	2	5.7	2	98	13.8	2	17.5	2	79	2.3	2	2.6	2	90
CRIS-342	4.9	2	6.0	2	81	12.2	2	13.7	2	89	2.6	2	2.7	2	97
Minimum	4.5		5.3	-	-	10.2	-	11.7	-	-	2.0	-	2.3	-	-
Maximum	8.2		8.3	-	-	21.2	-	23.8	-	-	3.4	-	3.5	-	-
Mean (u)	5.9		6.3	-	-	14.0	-	16.6	-	-	2.6	-	2.7	-	-
Standard deviation (STD)	1.2		1.0	-	-	3.6	-	4.0	-	-	0.5	-	0.4	-	-
u + STD	7.1		7.3	-	-	17.6	-	20.6	-	-	3.0	-	3.2	-	-
u - STD	4.6		5.3	-	-	10.4	-	12.6	-	-	2.1	-	2.3	-	-

Table 2. Seed cotton yield per plant (g) shoot B concentration (µg g^{-1}) of 10 cotton genotypes under deficient and adequate B in soil (Def. B, Adq. B and BER are deficient B, adequate B and B-efficiency-ratio, respectively). Values in bold following a genotype mean within each column are index scores (see Materials and Methods). Genotype means followed by similar index scores in a column are like in performance.

Genotype	Seed cotton yield plant^{-1}(g)					Shoot B Conc. (µg g^{-1})				
	Def. B	IS	Adq. B	IS	BER	Def. B	IS	Adq. B	IS	BER
IR-NIBGE-1524	30.0	2	37.7	2	79	73.3	2	92.5	2	79
MNH-886	33.2	2	45.9	2	72	69.2	2	79.2	1	87
CIM-506	48.2	2	55.2	2	87	63.5	1	94.8	2	67
SAU-2	51.5	3	58.7	3	88	66.1	2	94.7	2	70
Sindh-1	20.8	1	27.4	1	76	80.6	2	100.7	2	80
Chandi	26.7	2	48.8	2	55	70.9	2	113.8	3	62
NIA Ufaq	60.7	3	68.6	3	88	70.7	2	72.4	1	98
NIAB-78	28.5	2	31.0	1	92	86.4	3	107.2	2	81
NIAB-777	32.1	2	45.1	2	71	60.7	1	110.0	3	55
CRIS-342	31.9	2	36.8	2	87	82.4	3	102.7	2	80
Minimum	20.8	-	27.4	-	-	60.7	-	72.4	-	-
Maximum	60.7	-	68.6	-	-	86.4	-	113.8	-	-
Mean (u)	36.4	-	45.5	-	-	72.4	-	96.8	-	-
Standard deviation (STD)	12.7	-	12.9	-	-	8.4	-	13.1	-	-
u + STD	49.0	-	58.4	-	-	80.8	-	109.9	-	-
u – STD	23.7	-	32.7	-	-	64.0	-	83.7	-	-

Table 3. Boron uptake (µg seed cotton yield^{-1}) and B-use-efficiency (g^{2} seed cotton yield mg^{-1}seed cotton uptake) of 20 cotton genotypes under deficient and adequate B in soil (Def. B, Adq. B and BER are deficient B, adequate B and B-efficiency-ratio, respectively). Values in bold following a genotype mean within each column are index scores (see Materials and Methods). Genotype means followed by similar index scores in a column are like in performance.

Genotype	Seed cotton yield plant^{-1}(g)					Shoot B Conc. (µg g^{-1})				
	Def. B	IS	Adq. B	IS	BER	Def. B	IS	Adq. B	IS	BER
IR-NIBGE-1524	2200.4	2	3489.1	2	63	0.409	2	0.408	2	100
MNH-886	2297.7	2	3633.8	2	63	0.480	2	0.579	2	83
CIM-506	3060.5	2	5233.3	2	58	0.761	3	0.582	2	131
SAU-2	3400.0	3	5559.7	3	61	0.779	3	0.621	2	126
Sindh-1	1677.9	1	2755.7	1	61	0.258	1	0.272	1	95
Chandi	1892.2	2	5551.9	3	34	0.376	2	0.429	2	88
NIA Ufaq	4295.8	3	4969.4	2	86	0.858	3	0.947	3	91
NIAB-78	2464.1	2	3321.4	2	74	0.330	2	0.289	2	114
NIAB-777	1945.1	2	4961.4	2	39	0.528	2	0.410	2	129
CRIS-342	2628.1	2	3783.7	2	69	0.387	2	0.358	2	108
Minimum	1677.9	-	2755.7	-	-	0.258	-	0.272	-	-
Maximum	4295.8	-	5559.7	-	-	0.858	-	0.947	-	-
Mean (u)	2586.2	-	4325.9	-	-	0.517	-	0.490	-	-
Standard deviation (STD)	801.1	-	1033.6	-	-	0.210	-	0.201	-	-
u + STD	3387.3	-	5359.5	-	-	0.727	-	0.691	-	-
u – STD	1785.1	-	3292.4	-	-	0.307	-	0.288	-	-

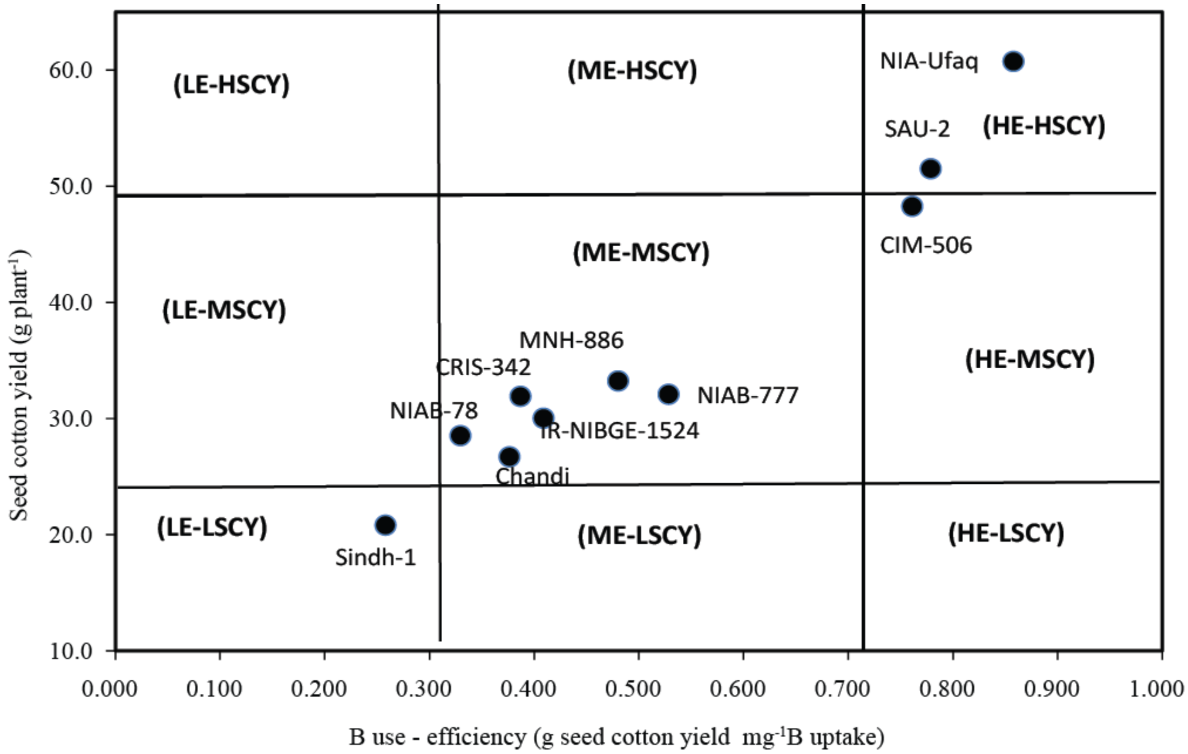

Fig. 2. Ranking of 20 cotton genotypes based on their B use efficiency at deficient B level (LE: low-efficient, ME: medium-efficient, HE: highly-efficient, LSCY: low seed cotton yield, MSCY: medium seed cotton yield, HSCY: high seed cotton yield). B use efficiency was calculated by the formula suggested by Siddiqi & Glass (1981). The ranking of genotypes was carried out by using the method of Gill *et al.* (2004).

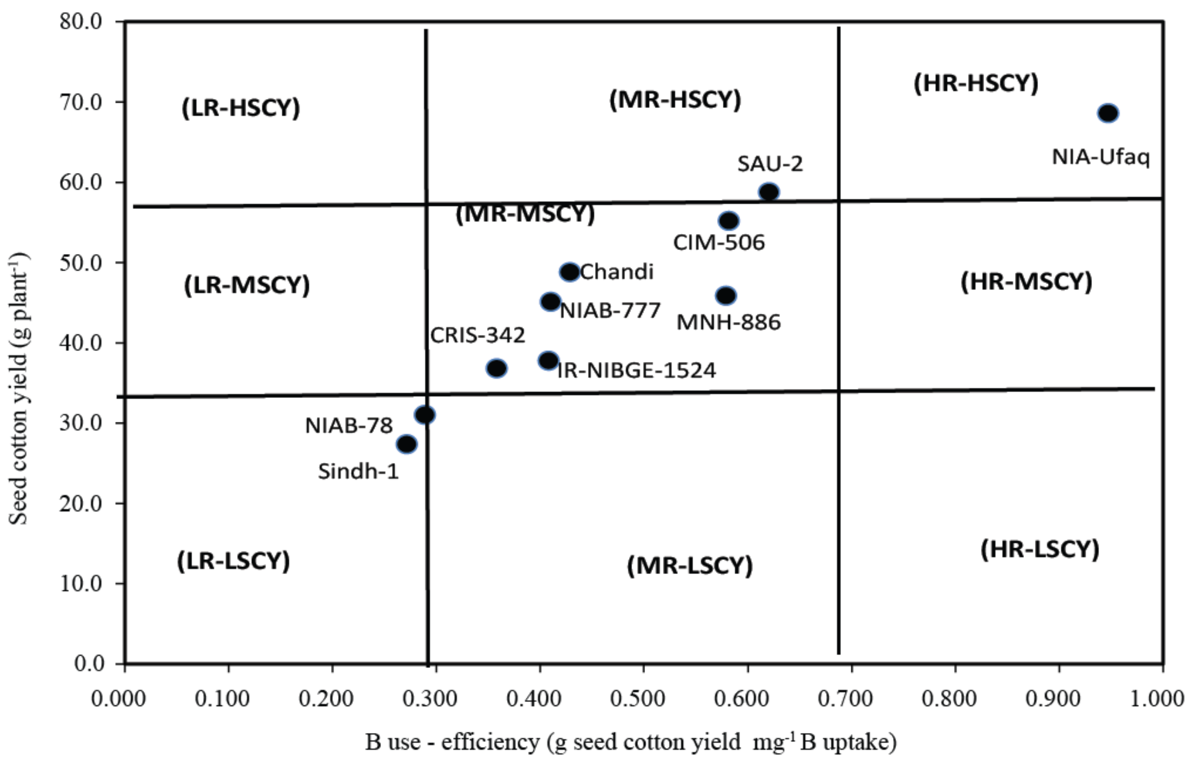

Fig. 3. Ranking of 20 cotton genotypes based on their B use efficiency at adequate B level (LE: low-efficient, ME: medium-efficient, HE: highly-efficient, LSCY: low seed cotton yield, MSCY: medium seed cotton yield, HSCY: high seed cotton yield). B use efficiency was calculated by the formula suggested by Siddiqi & Glass (1981). The ranking of genotypes was carried out by using the method of Gill *et al.* (2004).

Table 4. Relatively, ranking of 10 cotton genotype at deficient and adequate B regimes (LE: Low-efficient, ME: Medium-efficient, HE: Highly-efficient, LSCY: Low seed cotton yield, MSCY: Medium seed cotton yield, HSCY: High seed cotton yield).

Genotype	Gill *et al.* (2014)	
	Deficient B	Adequate B
IR-NIBGE-1524	ME-MSCY	MR-MSCY
MNH-886	ME-MSCY	MR-MSCY
CIM-506	HE-MSCY	MR-MSCY
SAU-2	HE-HSCY	MR-HSCY
Sindh-1	LE-LSCY	LR-LSCY
Chandi	ME-MSCY	MR-MSCY
NIA Ufaq	HE-HSCY	HR-HSCY
NIAB-78	ME-MSCY	LR-LSCY
NIAB-777	ME-MSCY	MR-MSCY
CRIS-342	ME-MSCY	MR-MSCY

Table 5. Correlation of seed cotton yield of ten cotton genotypes with numerous parameters at deficient and adequate B levels.

Parameters	Deficient B	Adequate B
Sympodia per plant	0.575NS	0.798**
Bolls per plant	0.819**	0.868**
Boll weight	0.672*	0.596NS
Shoot B content	-0.475NS	0.530NS
Boron uptake	0.954**	0.871**
Boron use efficiency	0.975**	0.932**

*, ** and NS indicate significant at $p<0.05$, $p<0.01$ and non-significant, respectively

Discussion

In order to assess the response of cotton genotypes to B-deficiency stress, ten cotton promising genotypes of Pakistan were test under B deficient and adequate conditions. These genotypes were categorized into different groups on the basis of their B-use-efficiency. Boron deficiency reduced seed cotton yield and its associated traits, B uptake and B use efficiency of all cotton genotypes at different rates (Fig. 1). This disparity in seed cotton yield, yield attributes, B uptake and B-use-efficiency showed the variation in adaptation of cotton genotypes to different B regimes and confirmed the results, accentuating the importance of adequate B nutrition of cotton (Anon., 2002; De Oliveira *et al.,* 2006). Boron as part of many physiological and biochemical, metabolic functions and enzymatic activities of plant (Hall, 2008), thus its deficiency severely decline various physiological and growth parameters of cotton like boll bearing, boll weight and seed cotton yield (Gupta & Hitesh, 2013). Similarly, here in or study B deficiency reduced sympodia per plant, bolls per plant, boll weight, which ultimately affected the seed cotton yield of cotton genotypes (Fig. 1; Tables 1 and 2).

Cotton cultivars differ in their B-use-efficiency (Fontes *et al.,* 2008). Relatively, B efficient cotton genotypes accrued more B in floral parts than B inefficient genotypes (Jian *et al.,* 2004). In this, genotypes NIA-Ufaq, SAU-2 and CIM506 were ranked as "highly-efficient" as these genotypes took up more B and produced more seed cotton yield under B-deficient condition as compared to "low-efficient" genotype Sindh-1 (Fig. 2; Table 4). Nevertheless, under B adequate condition only NIA-Ufaq was ranked as "highly-responsive" and NIAB-78, Sindh-1as "low-responsive" and remaining all as "medium responsive" (Fig. 3; Table 4). The results are in agreement with the finding of Zancanaro & Tessaro (2006) who found that Brazilian cotton genotype ITA 90 was more sensitive to B deficiency than cv. Fibermax 966. Moreover, Bogiani & Rosolem (2012) reported the genotypic variation among cotton cultivars in terms of time of start and magnitude of B deficiency symptoms. Recently, Tabatabaei & Noori (2014) found genotypic variation among four canola cultivars to B rates and reported that cultivar Likord required more B than Okapi to produce the maximum yield.

Conclusion

It is concluded from present studies that the NIA-Ufaq is "B-efficient-responsive" cotton genotype. It can be successfully grown under B deficient conditions without any additional B application as well as under B adequate conditions. Moreover, CIM-506 and SAU-2 are "highly efficient" which can be grown in B deficient soils deprived of B application. Sindh-1 is low-efficient-responsive" and remaining all are "medium-efficient" require slight application of B to produce the maximum harvest. The information will be helpful while selection of potential cotton genotypes.

Acknowledgement

I am grateful to Dr. Ameer Ali Mullah, Dr. Muhammad Athar Khan and Mr. Shafique Ahmed Abro for their valuable suggestions for the improvement of manuscript and statistical analysis. This study was a part of the Ph.D. dissertation research of first author.

References

Anonymous. 2002. B in cotton [Online] Available: http://www.borax. com/agriculture/files/cotton. pdf [May 15 2010].

Arain, M.A., A. Nazir, S.H. Siddiqui, S.K. Khanzada, S. Mumtaz A.W. Mangi and A. Khatri. 2008. Biennial progress report of NIA (2006-7 & 2007-8), pp. 36.

Baligar, V.C., N.K. Fageria and Z.L. He. 2001. Nutrient use efficiency in plants.communication in Soil *Science and Plant Aalysis*, 32: 921-950.

Bogiani, J.C. and C.A. Rosolem. 2012. Compared boron uptake and translocation in cotton cultivars. *Rev. Bras. Ciênc. Solo*., 36(5): 1499-1506.

Camacho-Cristobalj, J., M.B. Herrera-Rodriguez, V.M. Beato, J. Rexach, M.T. Navarro-Gochicoa, J.M. Maldonado and A. Gonzalez-Fontes. 2008. The expression of several cell wall-related genes in Arabidopasis roots in down-regulate under boron deficiency. *Enviorn. Exp. Bot*., 63: 351-358.

De Oliveira, R.H., C.R.D. Milanez, M.A. Moraes-Dallaqua and C.A. Rosolem. 2006. Boron deficiency inhibits petiole and peduncle cell development and reduces growth of cotton. *J. Plant Nutri*., 29: 2035-2048.

Fontes, R.L.F., F.M. Joaci, C.L.N. Julio, S.C. Orozimbo and C.M. Jose. 2008. Growth of brazilian cotton cultivars in response to soil applied boron. *J. plant Nutri*., 31(5): 902-918.

Gill, H.S., A. Singh, S.K. Sethi and R.K. Behl. 2004. Phosphorus uptake and use efficiency in different varieties of bread wheat (*Triticum aestivum* L.). *Archives in Agron. and Soil Sci*., 50: 563-572.

Gunes, A., A. Inal, M. Alpaslan and I. Cakmak. 2006. Genotypic variation in phosphorus efficiency between wheat cultivars grown under greenhouse and field conditions. *Soil Sci. and Plant Nutri*., 52: 470-478.

Gupta, U. and S. Hitesh. 2013. Impact of boron deficiency on plant growth. *Int. J. Bioassays*, ISSN: 2278-778X: 1048-1050.

Hall, D., Boron Fact Sheet. 2008. http://www.soilquality.org.au/factsheets/boron (Retrieved on 13th October, 2012 at 14:45pm).

Jian, M., L. Wu, X. Cao and W. Liu. 2004. Study on physiological characteristics of floral organ in two cotton cultivars with different boron efficiency. *Cotton Science*, 16(4): 206-210.

Mengel, K. and E.A. Kirkby. 2001. Boron. In: Principles of plant nutrition. 621-638, Kluwer Academic Publishers (5th ed.) Dordrecht/ Boston/ London, Netherlands.

Milka, B.J., M. Ivana, K.B. Marija, Z.S. Tijana, K.S. Ankica and K. Borislav. 2013. Boron concentration vs. content as criterion for estimating boron tolerance in wheat. *J. plant Nutri*., 36(3): 470-480.

Miwa, K., J. Takano, H. Omori, M. Seki, K. Shinozaki and T. Fujiwara. 2007. Plants tolerant of high boron levels. *Science*, 318(5855): 1417.

Nawaz, I., Zia-ul-Hassan, A.M. Ranjha and M. Arshad. 2006. Exploiting genotypic variation among fifteen maize genotypes of Pakistan for potassium uptake and use efficiency in solution culture. *Pak. J. Bot*., 38: 1689-1696.

Ponnamperuma, F.N., M.T. Caytan and R.S. Lantin. 1981. Dilute hydrochloric acid as an extractant for available zinc, copper, and boron in rice soils. *Plant Soil*, 61: 297-310.

Rashid, A. 2006. Boron deficiency in soils and crops of Pakistan: Diagnosis and Management. PARC, Islamabad, Pakistan.

Rengel, Z. and M.P. Damon. 2008. Crops and genotypes differ in efficiency uptake and use. *Physiologia Plantarum*, 133: 624-636.

Rerkasem, B., R.W. Bell, S. Lordkaew and J.F. Loneragan. 1993. Boron deficiency in soybean [*Glycine max* (L.) Merr.], peanut *(Arachis hypogaea* L.) and black gram [*Vigna mungo* L.) Hepper]: Symptoms in seeds and differences among soybean cultivars in susceptibility to boron deficiency. *Plant and Soil*, 150: 289-294.

Rosolem, C.A., J.A. Quaggio and N.M. Silva. 2001. Algodao, Amendoim e Soja. Pp. 321-354 In: (Eds.): Ferreira, M.E., Cruz. M.C.P., Raij, van. B., Abreu C.A. Mironutrients e element ostoxicosna agricultura. Jaboticabal: CNPq/FAPESP/POTAFOS>

Siddiqi, M.Y. and A.D. Glass. 1981. Utilization Index: A modified approach to the estimation and comparison of nutrient utilization efficiency in plants. *J. Plant Nutri*., 4: 289-302.

Tabatabaei, S.A. and G. Noori. 2014. Effect of different levels of boron on yield components of rapeseed varieties. *Asian J. Res. Soc. Sci. and Humanities*, 4(3): 407-417.

Zancanaro, L. and L.C. Tessaro. 2006. Calagem e adubação. In: Moresco, A. Algodão: Pesquisas e resultadospara o campo. Cuiabá, Fundo de Apoio à Cultura do Algodão/ FACUAL, p.56-81.

Zhang, Z., X. Tian, L. Duan, B. Wang, Z. He and Z. Li. 2007. Differential responses of conventional andbt-transgenic cotton to potassium deficiency. *J. Plant Nutri*., 30: 659-670.

Zia-ul-Hassan, K.A. Kubar, I. Rajpar, A.N. Shah, S.D. Tunio, J.A. Shah and A.A. Maitlo. 2014. Evaluating potassium-use-efficient of five cotton genotypes of Pakistan. *Pak. J. Bot*., 46(4): 1237-1242.

Zia-ul-Hassan, M. Arshad and A. Khalid. 2011. Evaluating potassium-use-efficient cotton genotypes using different ranking methods. *J. Plant Nutr*., 34: 1957-1972.

(Received for publication 27 July 2014)