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Effect of boron application time on yield of wheat, rice and cotton crop in Pakistan

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Abstract

Boron (B), one of the essential micronutrients, plays vital role in plant growth. Thirty one field experiments were conducted to evaluate the response of wheat, rice and cotton to B application throughout Pakistan during 2005-08. Boron was applied at 1 kg ha^{-1} as Borax decahydrate (11.3% B) at different times along with recommended doses of N, P and K. The results revealed that B application at sowing time to wheat increased significantly the number of tillers plant^{-1} (15%), number of grains spike^{-1} (11%), 1000-grain weight (7%) and grain yield (10%) over control. Among the treatments, B application at sowing time showed best results followed by B application at 1st irrigation and at booting stage. In rice (coarse), B application before transplanting substantially increased number of tillers hill^{-1} (21%), plant height (3%), panicle length (10%), and number of paddy grains panicle^{-1} (17%), 1000-grain weight (11%) and paddy yield (31%) over control. Response of fine rice to B application was similar for all yield parameters as in coarse rice. In cotton, B application considerably increased plant height (3%), number of mature bolls plant^{-1} (12%), seed weight boll^{-1} (8%) and seed cotton yield (9%) over control. Although, B application at all stages significantly increased yield parameters tested but B application at sowing time was best among all treatments.

Key words: Boron, sowing time, wheat, rice, cotton, yield parameters

Introduction

Boron, one of the essential micronutrients, plays vital role in plant growth. Being required by plants in minute quantities, it is classified as micronutrient; otherwise its role is as important as of any major plant nutrient, like nitrogen, phosphorus or potassium.

Fertilizer use in Pakistan predominately pertains to N and P. Potassium use is confined to a few high-K requiring crops like tobacco and potato. Micronutrient fertilizer use, in particular of B, is negligible. Moreover, continual removal of soil B in harvested crop parts and possible B loss through leaching depletes the meager soil and irrigation B supply thus, sooner or later, B must be replenished to sustain soil and crop productivity. Most of the cultivated soils in Pakistan have multiple nutrient deficiencies inclusive of B because of alkaline- calcareous nature, low organic matter content, nutrient mining with centuries old cropping pattern and inadequate and imbalanced fertilizer use (Rashid, 2006a).

Certain crops, like cotton, sunflower, legumes clover, lucerne, canola and pine have higher requirements than cereal crops (Shorrocks, 1997); hence, are susceptible to B deficiency and suffer yield losses in low B soils. Deficiency of B in soils of Pakistan is reported to be 50-60 % (Rashid *et al*., 2002).

Boron is required for normal development of reproductive tissues and deficiency results in low grain set or poor seed quality (Dell *et al*., 2002). Even the cereals (like wheat and rice) with small B requirement, can suffer from impaired seed set due to B shortage at a critical growth stage (Shorrocks, 1997). Consequently, among all micronutrients, deficiency of B is most frequently encountered in the field (Gupta, 1993). Experimental evidences in the country (Rashid *et al*., 2002; Rashid, 2006b) as well as international literature (Shorrocks, 1997; Gupta, 1993) suggest that the risk of B deficiency for crop production in Pakistan is increasing, prompting a need for careful B diagnosis, delineation of deficient areas, developing effective management strategies and enhancing awareness for its profitable use.

Keeping in view the importance of B in sustainable crop production, Fauji Fertilizer Company Limited (FFCL) conducted trials on effect of B application time on yield of wheat, rice and cotton. The aim of this study was to determine effect of different times of B application on major crops.

Material and Methods

Field experiments on wheat, rice and cotton crops were conducted at farmer’s fields in Sindh, Punjab and Khyber Pakhtunkhawa during 2005-08. Boron deficient soils were

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selected for the trials at all locations (Mirpur Khas, Dera Ismahil Khan, Jhang, Vehari and Ghakhar). Experiments were laid out in randomized complete block design (RCBD) NPK with three replications were used on soil test basis and general recommendation, respectively. The sources of NP and K were urea, DAP and SOP, respectively whereas 1 kg B/acre was applied as Sona Boron (Borax decahaydrate 11.3% -B). Basal fertilization included 124-135 kg N ha^{-1} as urea, 85-90 kg P ha^{-1} as DAP and 60 kg ha^{-1} as SOP in wheat, 124-148 kg N ha^{-1} as urea, 80-85 kg P ha^{-1} as DAP and 60 kg ha^{-1} as SOP in rice and 124-173 kg N ha^{-1} as urea, 85-90 kg P ha^{-1} as DAP and 30-60 kg ha^{-1} as SOP in cotton.

The experiment on wheat, rice and cotton crops were conducted at 15, 7 and 9 locations, respectively and three different B application times were tested for each crop. For wheat, B was applied at sowing, 1st irrigation and booting stages. For rice, B was applied before transplanting, at tillering and at booting stages. For cotton crop, B was applied at sowing, square formation and at flowering stages. Growth and yield parameters like no. of tillers $plant^{-1}$, plant height (cm), no. of grains $spike^{-1}$/$panicle^{-1}$, 1000-grain weight (g) and yield (kg ha^{-1}) were collected from wheat and rice crops, whereas plant height (cm), no. of mature bolls $plant^{-1}$, boll weight (g) and seed cotton yield (kg ha^{-1}) was recorded from cotton crop.

ECs were ranging between 0.18-0.56 dS m^{-1}, pH between 7.4-8.4, organic matter between 0.43-0.99%, available P between 3.0-9.00 ppm, extractable K between 60-316 ppm, Zn between 0.47-0.85 ppm, B between 0.26-0.63 ppm and Fe between 5.5-8 ppm.

The soil, were extracted by dilute HCl (Ponnamperuma *et al*., 1981) using spectrophotometer, and B in the extracts was measured colorimetrically using azomethine-H (Keren, 1996) while zinc and iron were determined by DTPA method using Atomic Absorption Spectrophotometer. The original soil B level was 0.26-0.63 ppm.

Data on yield determining parameters from each replication was collected by selecting 10 plants randomly in a zigzag fashion and then averaged. Data regarding 1000-grain weight was calculated by counting 1000 grains from each replication and weighing these grains on top load balance. Yield was recorded and converted to kg ha^{-1}. The data collected on various parameters were subjected to analysis of variance and the means obtained were compared by LSD at 5 percent level of significance (Steel and Torri, 1980).

Results and Discussion

Wheat

Boron application, irrespective of time, significantly increased number of tillers $pant^{-1}$ over control (Table 1). Maximum number of tillers per plant was observed in treatment where 3 kg sona Boron was applied at sowing time (15 % increase over control). Data showed that minimum number of tillers per plant was observed in

Table 1: Effect of B and its time of application on tillers $plant^{-1}$ of wheat

Treatment	Year			Mean	% Increase over control
	2005-06	2006-07	2007-08		
Control	3.83d	4.27bcd	4.29bcd	4.13	-
B at sowing	4.34abcd	4.96a	4.95a	4.75	15
B at 1st irrigation	4.19bcd	4.69ab	4.66ab	4.51	9
B at booting	4.02cd	4.58abc	4.58abc	4.39	6
LSD (0.05)			0.636		

Table 2: Effect of B and its time of application on plant height (cm) of wheat

Treatment	Year			Mean	% Increase over control
	2005-06	2006-07	2007-08		
Control	88.07d	93.29abc	93.17abc	91.51	-
B at sowing	89.29cd	93.82ab	94.36a	92.49	1.07
B at 1st irrigation	89.94bcd	93.63ab	94.05ab	92.54	1.13
B at booting	88.64abc	93.45ab	93.39d	91.82	0.34
LSD (0.05)			4.087		

Means followed by same letter(s) do not differ significantly.

Soil samples were collected from three different locations and composite samples were prepared in order to have true representation of the nutrient status of the trial site. Samples were analyzed for macro and micronutrient determination in FFC soil and water testing labs. The soil control and in treatment where B was applied at booting stage. These results are in line with other studies conducted by Qayyum *et al*. (1986), Bajwa (1988), Kauser *et al*. (1988), Hussain and Yasin (2004) and Khan *et al.* (2006). The reason for increased number of tillers per plant seems to be presence and utilization of B at required stages of plant growth.

Boron application has increased plant height in all the treatments as compared to control but statistically the difference among treatments is not significant (Table 2). The results of present study are also supported by Qayyum *et al*. (1986), Bajwa (1988), Kauser *et al*. (1988), Hussain and Yasin (2004) and Khan *et al*. (2006).

Table 3 depicts that B application at all three stages improved number of grains spike^{-1} but B application at sowing has significantly increased (11 %) number of grains spike^{-1} as compared to control. Arif *et al.* (2006) also reported that foliar application of B increased significantly number of grains spike^{-1} in wheat. As B application reduces spike sterility, this increase in grains may be due to reduced spike sterility.

Data presented in Table 4 revealed that maximum 1000- grains weight was obtained by the application of B at sowing time followed by B application at 1st irrigation and at booting stage. Minimum 1000-grains weight was observed in control. This may be due to provision of B at initial stages which might have enhanced the accumulation of assimilate in the grains and thus resulting in heavier grains of wheat (Arif *et al.,* 2006). These results are also in agreement with Qayyum *et al*. (1986), Bajwa (1988), Kauser *et al*. (1988), Iqtidar *et al*. (1979), Hussain and Yasin (2004) and Khan *et al*. (2006) who reported significant increase in 1000-grain weight with foliar application of micronutrients.

Maximum grain yield was recorded in treatment where B was applied at sowing followed by B application at 1st irrigation and at booting stages. Boron application at sowing increased yield by 10 % over control whereas this increase was 7 % and 3 % in case of B application at 1st irrigation and booting stage, respectively. Globally, positive crop responses to B application have been reported (Shorrocks, 1992). In Pakistan, Rashid, (2006a) has reported 5-14 % increase in yield with B use in wheat crop. As B application at sowing improved almost all yield parameters, this increase resulted in grain yield. Our results are also in agreement with previous studies (Table 5).

Rice

It is evident from Table 6 that B application at any time increased average number of tillers hill^{-1} over control. Maximum number of tillers hill^{-1} was observed by the application of B at sowing i.e. 21 % more number of tillers over control in coarse rice and 17% in fine rice. Minimum number of tillers hill^{-1} was observed when boron was applied at booting stage in case of both rice types. Ali *et al*., (1996) observed an increase in productive tillers plant^{-1} by B application. Qayyum *et al*. (1986), Bajwa (1988), Kauser *et al.* (1988), Hussain and Yasin (2004) and Khan *et al.* (2006) has also reported that B application increased plant height and number of tillers in wheat. The increase in

Table 3: Effect of B and its time of application number of grains spike^{-1} of wheat

Treatment	Year			Mean	% Increase over control
	2005-06	2006-07	2007-08		
Control	42.49bc	45.97abc	41.08c	43.18	-
B at sowing	48.11ab	49.32a	46.67abc	48.03	11
B at 1st irrigation	46.47abc	47.00ab	44.01abc	45.83	6
B at booting	43.68abc	46.16abc	42.59bc	44.14	2
LSD (0.05)			5.846		

Means followed by same letter(s) do not differ significantly.

Table 4: Effect of B and its time of application on 1000-grain weight (gm) of wheat

Treatment	Year			Mean	% Increase over control
	2005-06	2006-07	2007-08		
Control	44.19abcd	44.33abc	38.57e	42.36	-
B at sowing	46.08ab	47.55a	42.47bcde	45.37	7
B at 1st irrigation	45.74ab	44.61abc	40.88cde	43.74	3
B at booting	44.86abc	45.38ab	39.96de	43.40	3
LSD (0.05)			4.419		

Means followed by same letter(s) do not differ significantly

Table 5: Effect of B and its time of application on grain yield (kg ha^{-1}) of wheat

Treatment	Year			Mean	% Increase over control
	2005-06	2006-07	2007-08		
Control	3917g	4893bc	4153fg	4321	-
B at sowing	4267efg	5271a	4740cd	4759	10
B at 1st irrigation	4143fg	5126ab	4538de	4602	7
B at booting	4000g	4958abc	4423def	4461	3
LSD (0.05)			3.657		

Means followed by same letter(s) do not differ significantly.

Table 6: Effect of B and its time of application on tillers hill^{-1} of rice

Treatment	Coarse Variety				Fine Variety			
	Year		Mean	% Increase over control	Year		Mean	% Increase over control
	2006	2007			2007	2008		
Control	19b	20ab	19.5	-	29a	22b	25.5	-
B before transplanting	23a	24a	23.5	21	35a	25a	30.0	17
B at tillering	20ab	22ab	21.0	8	33a	23ab	28.0	10
B at booting	22ab	21ab	21.5	10	31a	22b	26.5	4
LSD (0.05)		4.548			5.834	2.116		

Means followed by same letter(s) do not differ significantly.

Table7: Effect of B and its time of application on plant height (cm) of rice

Treatment	Coarse Variety				Fine Variety			
	Years		Mean	% Increase over control	Years		Mean	% Increase over control
	2006	2007			2007	2008		
Control	104a	112a	108	-	116a	133a	125	-
B before transplanting	105a	116a	111	3	128a	138a	133	6
B at tillering	104a	114a	109	1	122a	136a	129	3
B at booting	105a	114a	110	2	120a	134a	127	2
LSD (0.05)		68.38			15.01	11.20		

Means followed by same letter(s) do not differ significantly.

Table 8: Effect of B and its time of application on panicle length (cm) of rice

Treatment	Coarse Variety				Fine Variety			
	Year		Mean	% Increase over control	Year		Mean	% Increase over control
	2006	2007			2007	2008		
Control	26ab	24b	25.0	-	23a	26d	24.5	-
B before transplanting	28a	27a	27.5	10	26a	29a	27.5	12
B at tillering	27a	26a	26.5	6	26a	28b	27.0	10
B at booting	26ab	25ab	25.5	2	26a	27c	26.5	8
LSD (0.05)		2.43			7.05	0.3629		

Means followed by same letter(s) do not differ significantly.

number of tillers plant^{-1} may be due to fulfillment of B deficiency at appropriate time (Mehmood *et al*., 2009).

Although data presented in Table 7 depicts that maximum increase in plant height was observed with B application before transplanting in both cultivars of rice but statistically, no significant increase in plant height was recorded.

Data presented in Table 8 shows that B application before transplanting and at tillering increased the panicle length over control significantly in coarse (10%) and fine

(12%) cultivars of rice. Minimum increase in panicle length has been recorded in treatment where B was applied at booting stage for both types of rice. This increase in panicle length is attributed to transportation of plant assimilates to all parts of plants in required quantity regulated by presence of B.

Table 9 depicts that boron application at all three stages has improved number of paddy grains spike^{-1} but B application before transplanting has significantly increased number of paddy grains panicle^{-1} in coarse (17%) varieties but increase in paddy grains panicle^{-1} was statistically not significant in fine rice as compared to no boron application. Although increase in number of grains panicle^{-1} in fine varieties was non significant statistically, but 14% increase in number of grains panicle^{-1} over control was recorded when B was applied before transplanting. Even B application at tillering has also increased paddy grains by 9% over control. This may be due to provision of B at initial stages which might have enhanced the accumulation of assimilate in the grains and thus resulting in heavier grains (Arif *et al.,* 2006).

The data regarding effect of B application on 1000-grain weight (Table 10) revealed that B application before transplanting increased 1000-paddy grains significantly in coarse and fine (13 %) rice followed by B application at tillering stage over control. In coarse as well as fine type minimum increase in 1000-grain weight has been recorded in case of B application at booting stage. As presence of B in plant regulates the translocation of assimilates to grains (Arif *et al.,* 2006), this might have resulted in increased 1000-grain weight.

Increase in paddy yield has been observed in all the treatments where B was applied as compared to control. Yield data of paddy presented in Table 11 revealed that maximum yield of 7150 kg ha^{-1} (coarse rice) was obtained where B was applied before transplanting indicating 31 % increase over control. In case of fine rice, the yield increase of 11% (4893 kg ha^{-1}) has been recorded in treatment where B was applied before transplanting. Maximum yield increase has been observed in B application before transplanting followed by B application at tillering (24% and 10%) and booting stages (7% and 3%) in coarse and fine cultivars, respectively.

Positive crop responses to B application have been reported worldwide. Soil application and foliar feeding are equally effective (Rashid, 2006a). Evidences indicate the response of rice to B (Kausar *et al*., 1991; Ali *et al*., 1996; Aslam and Qureshi, 1998) in Pakistan. Ali *et al*. (1996) observed an increase in productive tillers plant^{-1}, straw and paddy yield in rice with B application. The results of the present study are also in agreement with Khan *et al*. (2006) and Mehmood *et al*. (2009) who have observed significant increase in paddy yield by B application. They reported that number of spikes m^{-2}, number of spikes plant^{-1}, spike

Table 9: Effect of B and its time of application on number of paddy grains panicle-1 of rice

Treatment	Coarse Variety				Fine Variety			
	Year		Mean	% Increase over control	Year		Mean	% Increase over control
	2006	2007			2007	2008		
Control	106b	109ab	107.5	-	82a	137a	109.5	-
B before transplanting	122ab	129a	125.5	17	93a	156a	124.5	14
B at tillering	113ab	120ab	116.5	8	89a	150a	119.5	9
B at booting	107ab	117ab	112.0	4	87a	144a	115.5	5
LSD (0.05)	23.44				19.52	27.71		

Means followed by same letter(s) do not differ significantly.

Table 10: Effect of B and its time of application on 1000-grain weight (gm) of rice

Treatment	Coarse Variety				Fine Variety			
	Year		Mean	% Increase over control	Year		Mean	% Increase over control
	2006	2007			2007	2008		
Control	22d	23c	22.5	-	20a	20c	20.0	-
B before transplanting	25ab	26a	25.5	13	22a	23a	22.5	13
B at tillering	25b	25b	25.0	11	21a	21b	21.0	5
B at booting	23c	24bc	23.5	4	21a	20bc	20.5	3
LSD (0.05)	0.872				3.346	1.011		

Means followed by same letter(s) do not differ significantly.

length, plant height and 1000- grain weight of paddy were significantly affected by B application over control. Rashid *et al*. (2006b) reported 14-30% overall increase in paddy yield by B application. In fine varieties (Super Basmati, Basmati-385 and KS-282) yield increase due to B application has been observed up to 25% in Punjab and IR-6 variety in Sindh province. Yield increase with B occurred because of reduced panicle sterility (on lower portion of the ear) and increased productive tillers hill^{-1}. Use of B not only enhances paddy yields appreciably but also increases kernel milling recovery and head rice recovery as well as improve cooking quality traits. Improvement in cooking quality of rice, with better B nutrition of plants, is attributed to better grain filling and uniform crop maturity (Rashid *et al*., 2006a).

Cotton

Statistically B application has not increased plant height significantly. But, B application at sowing increased plant height by 3 % over control and no increase has been observed in treatment where B was applied at square formation stage (Table 12). However, 1 % increase in plant height has been observed when B was applied at flowering stage. Soil applied B is readily absorbed by plant root, rapidly translocated to the growing tips of plants and thus is well distributed throughout the plant (Shorrocks, 1992; Abid *et al*., 2007). This equal distribution might have played role in increasing the plant height, higher number of nodes on main stem which ultimately resulted in greater number of sympodia (fruiting branches), higher foliage and large plant structure (Zhao and Oosterhuis, 2003), because B is directly or indirectly involved in many physiological processes during plant growth, such as cell elongation and cell division (Blevins and Lukaszewski, 1998).

Data on number of mature bolls plant^{-1} presented in Table 13 illustrate that there is no significant increase in number of mature bolls due to B application. However, maximum number of mature bolls plant^{-1} (12%) were achieved in treatment where B was applied at sowing time followed by B at square formation (7%) and at flowering (5%). Presence of B in plants reduces flower sterility and enhances the fertilization process which result in increased number of bolls. Boron application at sowing equally distributes B in plant body. This equal distribution might have played role in increasing higher number of nodes on main stem which ultimately resulted in greater number of sympodia (fruiting branches), higher foliage and large plant structure (Zhao and Oosterhuis, 2003).

The data in Table 14 indicate that B application at sowing gave the highest average seed cotton weight boll^{-1} i.e. 3.47 g followed by boron application at square formation stage (3.38 g). Maximum seed cotton weight boll^{-1} was obtain by the application of boron at sowing during 2008 (3.94 g), whereas minimum seed cotton boll weigh was obtained during 2007 in control (2.61 g) where no boron was applied. On overall basis, application of boron significantly increased seed cotton weight boll^{-1} when compared with control using LSD at 5%. Boron application at sowing, square formation and flowering stage increased

Table 11: Effect of B and its time of application on paddy yield (kg ha^{-1}) of rice

Treatment	Coarse Variety				Fine Variety			
	Year		Mean	% Increase over control	Year		Mean	% Increase over control
	2006	2007			2007	2008		
Control	5426d	5494d	5460	-	4151b	4646c	4398	-
B before transplanting	7282a	7424a	7150	31	4448a	5337a	4893	11
B at tillering	6985b	7018b	7002	24	4349a	5041b	4695	7
B at booting	5922c	6052c	5987	10	4250ab	4843bc	4547	3
LSD (0.05)	200.2				217.5	2.522		

Means followed by same letter(s) do not differ significantly.

Table 12: **Effect of B and time of application on plant height (cm) of cotton**

Treatment	Year			Mean	% Increase over control
	2006	2007	2008		
Control	136a	134a	130a	133	-
B at sowing	136a	144a	132a	137	3
B at square formation	130a	138a	133a	134	1
B at flowering	135a	134a	132a	134	1
LSD (0.05)	30.25				

Means followed by same letter(s) do not differ significantly.

Table 13: Effect of B and its time of application on number of mature bolls plant^{-1} of cotton

Treatment	Year			Mean	% Increase over control
	2006	2007	2008		
Control	53a	42a	30a	42	-
B at sowing	56a	50a	35a	47	12
B at square formation	55a	48a	33a	45	7
B at flowering	54a	46a	31a	44	5
LSD (0.05)	31.54				

Means followed by same letter(s) do not differ significantly.

Table 14: Effect of B and its time of application on seed cotton weight boll^{-1} (gm) of cotton

Treatment	Year			Mean	% Increase over control
	2006	2007	2008		
Control	3.42bc	2.61d	3.60ab	3.21	-
B at sowing	3.51ab	2.98cd	3.94a	3.47	8
B at square formation	3.53ab	2.87d	3.76ab	3.38	6
B at flowering	3.43bc	2.79d	3.70ab	3.30	3
LSD (0.05)		0.4789			

Means followed by same letter(s) do not differ significantly.

Table 15: Effect of B and time of application on Seed Cotton Yield (kg ha^{-1}) of cotton

Treatment	Year			Mean	% Increase over control
	2006	2007	2008		
Control	2581b	2852ab	3512ab	2981	-
B at sowing	2625b	3250ab	3898a	3258	9
B at square formation	2571b	3099ab	3714ab	3124	5
B at flowering	2619b	2939ab	3605ab	3054	3
LSD (0.05)		12.75			

Means followed by same letter(s) do not differ significantly.

seed cotton weight boll^{-1} by 8%, 6% and 3 %, respectively, over control. Cotton yield depend on number of bolls produced per unit area and boll weight (Sawan *et. al.*, 2002). These results confirm the findings of earlier research that yield increase was the consequence of enhanced seed setting and boll weight (Rashid *et al*., 2002; Abid *et al*., 2007).

The seed cotton yield data (Table 15) indicate that B application at sowing gave the highest average yield of 3258 kg ha^{-1} and this was 9% increase over control. Whereas, B application at square formation and at flowering stage increased seed cotton yield by 5% and 3%, respectively, over control. Yield increases with improved B nutrition of cotton occurred due to increased boll weight as well as boll bearing. Increase in number of mature bolls and seed cotton weight boll^{-1} has been observed with B application. As B regulates translocation of assimilates to the plant part where these are required, this translocation in optimum quantities might have resulted in better boll weight and ultimately seed cotton yield. These results are supported by previous studies as well (Shorrock, 1992; Rashid *et al*., 2002; Abid *et al*., 2007).

Conclusion

Soil application of B fertilizer has positive impact on the yield and different yield components of wheat, rice and cotton crop. Soil application not only significantly increases yield of these crops but it is also economical and easy to use for the farmers. Furthermore, soil application of B fertilizer leaves a beneficial residual effect on succeeding crops in the same field. Although B application is generally recommended at sowing, if due to any reason, B is not applied at sowing or transplanting, even then it is economically viable to apply B at 1st irrigation in wheat, at tillering in rice and at square formation in cotton.

References

Abid, M., N. Ahmad, A. Asghar, M. A. Chaudhry and J. Hussain. 2007. Influence of soil-applied boron on yield, fiber quality and leaf boron contents of cotton

(*Gossypium hirsutum* L.). *Journal of Agriculture and Social Science* 3(1): 7-10.

Ali, A., M.S. Zia, F. Hussain and M.B. Khan. 1996. Boron requirements of rice and its management for rice production. *Pakistan Journal of Soil Science* 2: 68-71.

Arif, M., M.A.Chohan, S. Ali, R. Gul and S. Khan. 2006. Response of wheat to foliar application of nutrients. *Journal of Agriculture and Social Science* 1(4): 30-34.

Aslam, M. and R.H. Qureshi. 1998. Fertilizer management in salt affected soils for high productivity. p. 89-109 *In:* Proceeding Symposium on Plant Nutrition Management for Agricultural Growth. N. Ahmed and A. Hammed (eds.). NFDC, FAO and IMPHOS, December 8-10, 1997, Islamabad, Pakistan.

Bajwa, M.I. 1988. Micro nutrients fertilizers in Pakistan. p: 270–276. *In:* Proceeding National Seminar on Micro Nutrients in Soils and Crops in Pakistan, December 13-15, 1988. NWFP Agriculture University, Peshawar.

Blevins, D.G. and K.M. Lukaszewski. 1998. Boron in plant structure and function. *Annual Review of Plant Physiological and Molecular Biology* 49: 481–500.

Dell, B., L. Huang and R.W. Bell. 2002. Boron in plant reproduction. p. 103-108 *In:* Boron in plant and Animal Nutrition, H.E. Goldbach B. Rerkasem, M. Wimmer, P.H. Brown, M. Thellier and R.W. Bell (eds.). Kluwer Academic/Plenum Publishers, New Yark.

Hussain, F. and M. Yasin. 2004. Soil Fertility Monitoring and Management in Rice-wheat System. *Annual Report*, LRRP, NARC, Islamabad. p. 1-33.

Iqtidar, A., J.K. Khattak, S. Parveen and T. Jabeen. 1979. Effect of Boron on the yield and protein contents of wheat. Pakistan *Journal of Science and Indian Research* 22: 248-250.

Gupta, U.C. 1993. Boron and its role in crop protection. CRC Press. p. 208-224.

Kauser, M.A., M. Tahir and M. Sharif. 1988. Wheat response to field application of boron and evaluation of various methods for the estimation of soil boron. p: 132–138. *In:* Proceeding National Seminar on Micronutrients in Soils and Crops in Pakistan. December 13–15, 1988. NWFP Agriculture University, Peshawar.

Kausar, M.A., M. Tahir and A. Hamid. 1991. Rice response to high soil B and role of Ca^{2+} in B tolerance of rice. *Pakistan Journal of Soil Science* 6: 1-4.

Keren, R. 1996. Boron. p. 603-626. *In:* Methods of Soil Analysis, part 3: Chemical Methods. D.L. Sparks, A.L. Page, P.A. Helmke, R.H. Loeppert, P.N. Soltanpour, M.A. Tabatabai, C.T. Johnson and M.E. Summer (eds.). Soil Science Society of America, Madison, Wisconsin, USA.

Khan, R., A.H. Gurmani, A.R. Gurmani and M.S. Zia. 2006. Effect of boron application on rice yield under wheat rice system. *International Journal of Agriculture and Biology* 8 (6): 805-808.

Mehmood, E., R. Kausar, M. Akram and S.M. Shazad. 2009. Is boron required to improve rice growth and yield in saline environment? *Pakistan Journal of Botany* 41(3): 1339-1350.

Ponnamperuma, F.N., M.T. Caytan and R.S. Lantin. 1981. Dilute HCl as an extractant for available zinc, copper and boron in rice soils. *Plant Soil* 61: 279–310.

Qayyum, F., M. Tahir, J.K. Khattak and A. Shahid. 1986. Soil Status and Scope of Micro-nutrients in Pakistan Agriculture. Publication. NARC, Islamabad. p. 1-36.

Rashid, A., E. Rafique and J. Ryan. 2002. Establishment and management of boron deficiency in crops in Pakistan: A country report. p: 339–48. *In:* Boron in Plant and Animal Nutrition. H.E. Goldbach B. Rerkasem, M. Wimmer, P.H. Brown, M. Thellier and R.W. Bell (eds.). Kluwer Academic Publication, New York, USA.

Rashid A. 2006a. Incidence, diagnosis and management of micronutrient deficiencies in crops: Success stories and limitations in Pakistan. Invited paper. Proceeding IFA International Workshop on Micronutrients, 27 February, 2006. Kunming, China.

Rashid, A. 2006b. Boron Deficiency in Soils and Crops of Pakistan, Diagnosis and Management. Pakistan Agriculture Research Council, Islamabad. 34p.

Sawan, Z.M., L.I. Hanna, A.G.E. Karim and W.L. McCuistion. 2002. Relationships between climatic factors and flower and boll production in Egyptian cotton (*Gossyium barbadense*). *Journal of Arid Environment* 52: 499–516.

Shorrocks, V.M. 1992. Boron-A global appraisal of the occurrence, diagnosis and correction of boron deficiency. p: 39–53. *In:* Proceeding International Symptoms on the Role of Sulphur, Magnesium and Micronutrients in Balanced Plant Nutrition. S. Portech (ed.). The Sulphur Institute, Washington, D.C.

Shorrocks, V.M. 1997. The occurance and correction of boron deficiency. *Plant and Soil* 193: 121-148.

Steel, R.G.D. and J.H. Torri. 1980. Principals and Procedures of Statistics, 2nd Ed. McGraw Hill Book Company Inc. New York.

Zhao, D. and D.M. Oosterhuis. 2003. Cotton growth and physiological responses to boron deficiency. *Journal of Plant Nutrition* 26: 856–867.