ISSN 0258-7122 (Print), 2408-8293 (Online)
Bangladesh J. Agril. Res. 43(3): 453-469, September 2018

EFFECTS OF DIFFERENT METHODS AND TIME OF BORON APPLICATION ON THE NUTRIENT CONCENTRATION AND UPTAKE BY WHEAT (*Triticumaestivum* L.)

O. A. FAKIR[1], M. K. ALAM[2], M. J. ALAM[3]
M. JAHIRUDDIN[4], AND M. R. ISLAM[5]

Abstract

At present, inclusion of Boron (B) in fertilizer management practice most often determines the yield performance of crops. Methods of supply of B to plants demands more research to come to a conclusion. The effect of different methods of boron application on the nutrient concentration and uptake of wheat (*Triticuma estivum* L.*cv.* Shatabdi) was studied through a field experiment at Bangladesh Agricultural University (BAU) farm, Mymensingh during *rabi* season of 2012-13. The experiment was laid out in a randomized complete block design (RCBD) with six treatments and three replications. The treatments were- (i) B–control (no addition of B), (ii) soil application @ 1.5 kg ha^{-1}, (iii) seed priming @ 0.4% boric acid solution, (iv) foliar spray @ 0.4% boric acid solution at primodia stage (37DAS), (v) foliar spray @ 0.4% boric acid solution at booting stage (55 DAS),and (vi) foliar spray at primodia stage (37DAS) and booting stages (55 DAS). Boric acid was used as a source of boron. Seed priming was done by soaking wheat seeds into 0.1% boric acid solution for 10 hours and then seeds were dried before sowing. Foliar spray of B at primodia and booting stage of crop (T_6) recorded the highest B concentration of grain (19.60 µg g^{-1}) and the control (T_1) treatment performed the lowest B concentration (6.75 µg g^{-1}). Similarly, the foliar spray of B at primodia and booting stages of crop (T_6) recorded the highest B uptake by both grain and straw that was statistically identical to foliar spray of B at booting stage of crop (T_5) in both cases. In view of cost-return analysis, foliar spray of B at primodia and booting stage treatment required the highest input cost but obtained the highest gross return, while control B required the lowest input cost along with lowest gross return.

Keywords: Bangladesh; Foliar application of B; Seed priming of B, Soil application of B; Wheat.

Introduction

Wheat growing soils were reported to be B deficient in different areas keeping in with the dissemination of semi-dwarf wheat varieties in the 1960s (Rerkasem

[1,2&3]Scientific Officer, Bangladesh Agricultural Research Institute (BARI), Bangladesh, [4&5]Professor, Department of Soil Science, Bangladesh Agriculture University (BAU), Mymensingh, Bangladesh.

and Jamjod, 2004). According to Shorrocks (1997), B deficiency in wheat soils were found in countries like India, Pakistan, Bangladesh, Nepal, China, Thailand, Brazil, Bulgaria, Sweden, Finland, Madagascar, South Africa, Tanzania, Zambia, USA and Yugoslavia. In Asia, the B deficiency prone soils were discovered in and around eastern Nepal, north-eastern India and north-western Bangladesh, through to south-western China (Bhatta and Ferrara, 2005). The growth and yield of wheat, a crop which is growing worldwide, responds significantly to B application (Chakraborti and Barman, 2003; Soylu and Topal, 2004). A study in Pakistan identified the response of wheat to B in non-irrigated fields (Chaudhry *et al.*, 2007). They also reported that wheat yield increasewith the application of B. Soils with low organic matter, coarse in texture, high pH, prolonged dry condition, soils under intensive cultivation, containing less micronutrients and nutrient mining can be turned into B deficient soils (Rashid *et al.*, 2005; Mengel and Kirkby, 2001; Niaz *et al.* 2007).As wheat is growing in every part of the world, the deficiency may also be found in new and new areas over time. How to correct these should be studied efficiently. Ahmad *et al.* (2012) reported that correcting B deficiency in soils by external application can result in increased yield of crops with quality. The crop yield on B deficient soils depends on sources, rates, formulations and timing and B application methods in soil/to plants. Soil and/or foliar application methods of B are effective in improving crop yield, quality, content and uptake of B (Ahmad *et al.*, 2012).

With the frequent application of B to soil, the chances of B toxicity is huge and a very thin difference in between deficiency and toxicity reported by (Cooke 1982). Thus, a careful and judicious application of boron is necessary. Efficiency of B application depends on the time and method of application. Mahler (2010) and Marphy and Walsh (1972)put emphasis on B application for several times over the crop growing season. The reason may be immobile B is essential to be available at all growth stages, mainly during fruit/seed development stages.

Boron may have influenced on the absorption of cations and anions and on carbohydrate and nitrogen metabolism (Batey, 1971, Bonilla *et al*. 1980, Pollard *et al*. 1977). There are many reports on the positive response of crops to B application (Ahmed *et al.*, 1991; Jahiruddin *et al.*, 1995; Haque *et al.*, 2000). Soil application is a common practice of B fertilizer supply for most of the crops. For micronutrients when plants receive small amount, other methods like foliar spray and seed priming might be equally effective as soil application. Further, the latter two methods would be more economic since they will require much smaller amount of boron. Foliar spray of boron could be better for two reasons – (i) the amount of B fertilizer would be at least five times less and (ii) T.aman rice generally does not respond to B application, so residual effect of soil applied B would be of no value.

With the above understanding, a study was made to evaluate the effect of different methods of B application on the nutrient concentration and uptake of wheat (*Triticum aestivum* L.*)* at (i) BAU farm, Mymensingh (ii) Agro-ecological Zone-9).The present investigation also aimedto determine the best time and method of foliar application of boron for overcoming B deficiency and obtaining higher crop yield.

Materials and Methods

Experimental site

The experiment was conducted at the Soil Science Field Laboratory of Bangladesh Agricultural University (BAU) farm, Mymensingh during 2012-13. The experimental field is located at 24.75° N latitude and 90.50° E longitude at a height of 17 m above the mean sea level. It was a medium high land. The soil was Sonatala silt loam, a member of *Aeric Haplaquept*. It belongs to the order Inceptisol having only few horizons, developed under aquic moisture regime. General characteristics of the soil are presented in Table 1 (A, B and C).

Table 1. Morphological, physical and chemical characteristics of the soil

A. Morphological characteristics

AEZ	Old Brahmaputra Floodplain (AEZ-9)
General soil type	Non-calcareous Dark Grey Floodplain Soils
Parent materials	Brahmaputra river borne deposits
Drainage	Moderate
Topography	Medium high land
Flood level	Above flood level

B. Physical characteristics

% Sand	20.4
% Silt	68.0
% Clay	11.6
Textural class	Silt loam

C. Chemical characteristics

Characteristics	Content	Interpretation
pH (soil: water = 1:2:5)	7.30	Near neutral
Organic matter (%)	0.81	Very Low
Total N (%)	0.06	Low
Available P (mgkg^{-1})	7.29	Low
Available K (c mol kg^{-1})	0.06	Low
Available S (mg kg^{-1})	10.0	Low
Available Zn (mg kg^{-1})	0.84	Low
Available B (mg kg^{-1})	0.15	Low

Climate

The experimental area has a sub-tropical humid climate, which is characterized by high temperature, high humidity and high rainfall with occasional gusty winds in the kharif season and low rainfall associated with moderately low temperature during rabi season (Table 2).

Table 2. Monthly recorded temperature, relative humidity, rainfall and sunshine during thecropping period from November 2012 to March 2013

Year	Months	Air temperature (^{o}C)**			Relative humidity (%)**	Rainfall (mm)*	Sunshine (hrs)*
		Maximum	Minimum	Average			
2012	November	29.35	18.63	23.99	82.80	Trace	204.7
	December	25.44	13.26	19.35	85.45	00.0	174.6
	January	24.00	11.70	17.85	82.87	00.0	240.3
2013	February	27.71	14.88	21.30	75.11	04.1	196.8
	March	31.95	20.72	26.34	74.54	16.2	210.9

* Monthly total, ** Monthly average

Source: Weather Station, BAU, Mymensingh

Crop

The crop under study was wheat and the variety used was *Shatabdi* developed by Bangladesh Agricultural Research Institute (BARI), Gazipur. The seeds were collected from Wheat Research Centre (WRC), Dinajpur.

Experimental design

The experiment was laid out in a randomized complete block design (RCBD). There were six boron treatments, each replicated three times. The number of plots was 6×3 = 18. The unit plot size was 4 m×5m. The plot- to- plot distance was 0.5 m and block - to- block distance was 1 m.

Treatments

The six boron treatments were as follows:

T_1 = Control

T_2 = Soil application of B @ 1.5 kg ha^{-1} (designated as SA)

T_3 = Seed priming (wheat seed soaked in 0.1% boric acid solution for 10 hours before sowing (designated as SP)

T_4 = Foliar spray @ 0.4% boric acid solution at primodia stage (37 DAS) of crop growth (designated as FS-p)

T_5 = Foliar spray @ 0.4% boric acid solution at booting stage (55 DAS) of crop growth (designated as FS-b).

T_6= Foliar spray at primodia and booting stages (designated as FS-pb).

Fertilizer application

Fertilizers were applied to each plot as per treatments. Besides boron, every treatment received 115 kg N ha^{-1}, 25 kg P ha^{-1}, 75 kg K ha^{-1} and 15 kg S ha^{-1}. Fertilizers such as urea, TSP, MoP, gypsum and boric acid were used as sources for N, P, K, S, and B, respectively. One-third dose of urea and full dose of all other fertilizers were applied as basal to the individual plots during final land preparation. Fertilizers were incorporated into soil by hand. The second split of urea was applied after 30 days of sowing (crown root stage) and the third split after 55 days (booting stage). Boron was applied as per treatments. For foliar spray treatments, boric acid solution was sprayed at 37 and 55 days after sowing to represent primodia and booting stages of crop, respectively.

Intercultural operations

Topdressing of urea was done as per schedule and the normal cultural practices including weeding and insecticide spray were done as and when required. Two irrigations were provided after 25 and 55 days of sowing. Weeding was done twice during the whole growth period, the one after 21 days of sowing and the other after 50 days. The field was attacked by armyworm (*Mythumnaseparata*) which was successfully controlled by using Akonazol.

Data collection

At harvest of the crop, ten plants were randomly collected from each plot. The data were then converted to grain and straw yield per plot. After oven-drying overnight at 105ºC, the dry biomass of the grain and straw yields were recorded for chemical analysis and uptake calculation.

Chemical analysis

The total N content of wheat grain and straw was measured following the Kjeldahl method. The P concentration was determined colorimetrically at 660 nm wavelength by developing blue colour with ammonium molybdate reagent. The concentration of K was determined directly by a flame photometer. The S concentration in the digest was determined turbidimeterically and the turbid was measured by spectrophotometer at 420 nm wavelengths and the concentration of boron estimated colorimetrically after colour development by azomethine-H method.

Calculation of uptake

The uptake of N, P, K, S and B were determined by multiplying with dry biomass of straw and grain by their corresponding specific nutrient content in straw and grain, respectively.

Statistical analysis

The analysis of variance (ANOVA) for various crop characters and also for nutrient concentrations and uptake were done following the principle of F-statistics. Mean comparison of the treatments were adjudged by the Duncan's Multiple Range Test (Gomez and Gomez, 1984). Correlation statistics was performed to examine the interrelationship among the plant characters under study.

Results and Discussion

A. Results

Effects of different methods of boron application on the nutrient concentration of wheat

Nitrogen concentration

The N concentration of wheat grain was significantly influenced by B application ($p < 0.05$; Figure 1). This indicates that B helps in protein synthesis. The N concentration in grain varied from 1.23% to 1.79%; the lowest N concentration found with B control and the highest concentration by soil application @ 1.5 kg B ha^{-1}(T_2).Like grain N- concentration, the straw N concentration varied among B application treatments ($p > 0.05$). All the B treatments (T_2 to T_6) showed identical straw N concentration.

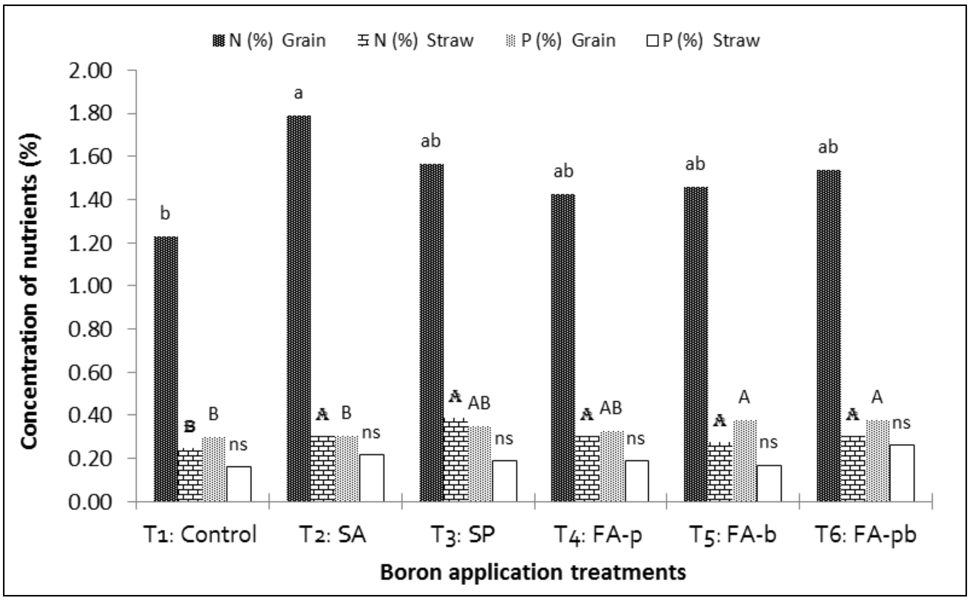

Fig. 1. Effects of different methods of applicationon the N and P concentrations of wheat grain and straw.

Standard error (SE±) for N in grain and straw and P in grain and straw were 0.03, 0.01, 0.001 and 0.001, respectively. Values in a column having same letter do not differ significantly at 5% level by DMRT

NS = Not significant

S.E = Standard error of means

SA = Soil application @ 1.5 kg B ha^{-1}

SP = Seed priming with 0.1% boric acid solution for 10 hours

FA-p= Foliar spray @ 0.4% boric acid solution at primodia stage (37 DAS) of crop.

FA-b=Foliar spray @ 0.4% boric acid solution at booting stage (55 DAS) of crop.

FS-pb = Foliar spray @ 0.4% boric acid solution at primodia and booting stage of crop.

Phosphorus concentration

Boron application had significant and positive effect on the grain P concentration of wheat ($p < 0.05$; Figure 1). The grain P concentration varied from 0.3 to 0.38%.The lowest value was noted in control treatment and the highest in foliar applied B at booting stage of the crop. The straw P concentration remained unaffected due to Bapplication ($p > 0.05$).

Potassium concentration

The K concentration of wheat grain was not significantly varied with B ($p > 0.05$; Figure 2). The grain K concentration over the treatments was 0.31% to 0.33%.

The highest grain-K concentration was recorded in soil application of B (T_2) and the lowest was observed in B control (T_1). The straw–K concentration significantly varied with B application method ($p < 0.05$; Figure 2). The maximum straw-K concentration was recorded with B applied as foliar spray at booting stage and the minimum was noted in control treatment.

Sulphur concentration

There was no significant effect of applied B on sulphur concentration of wheat grain (Figure 2).The grain S concentration was 0.12% - 0.16% over the six B treatments. The highest grain-S concentration (0.16%) was recorded with seed priming treatment (T_3) and the lowest grain S-concentration demonstrated by B control treatment. Unlike grain S, the S concentration significantly varied with B treatments (Figure 2). It ranged from 0.02% noted in control to 0.06% in foliar applied B at primodia and booting stages of crop.

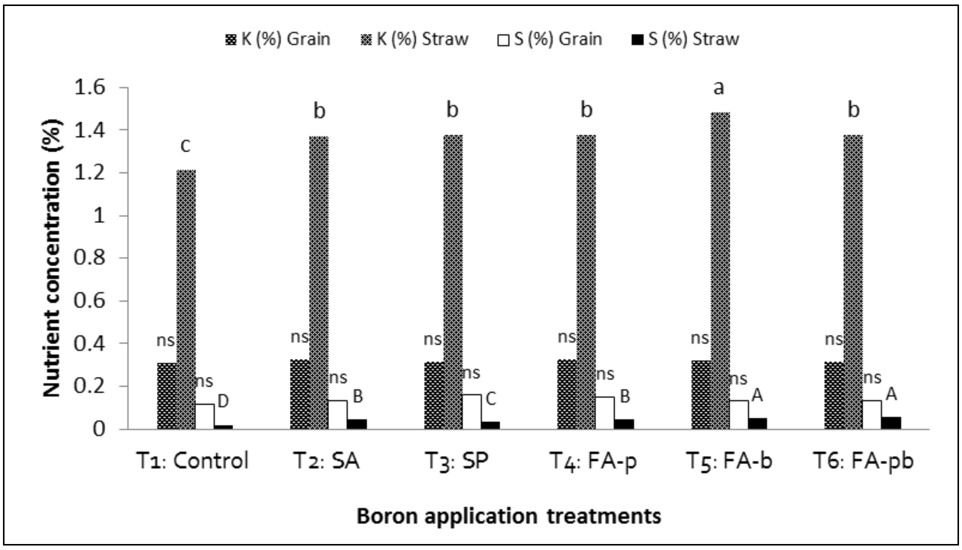

Fig. 2. Effects of different methods of applicationon the K and S concentrations of wheat grain and straw. SE(±)) for K in grain and straw and S in grain and straw were 0.0002, 0.004, 0.0001 and 0.0001, respectively.Values in a column having same letter do not differ significantly at 5% level by DMRT

NS = Not significant

SE = Standard error

SA = Soil application @ 1.5 kg B ha^{-1}

SP = Seed priming with 0.1% boric acid solution for 10 hours

FA-p= Foliar spray @ 0.4% boric acid solution at primodia stage (37 DAS) of crop.

FA-b=Foliar spray @ 0.4% boric acid solution at booting stage (55 DAS) of crop.

FS-pb = Foliar spray @ 0.4% boric acid solution at primodia and booting stages of crop.

Boron concentration

Boron concentration in grain varied with different methods of B application ($p < 0.05$; Figure 3). This result was expected because the soil was deficient in B. Comparing the methods of B application, foliar spray at primodia and booting stages of crop (T_6) showed the highest B concentration (19.6µg g^{-1}) that was` statistically identical with foliar spray at booting stage of crop (T_5). The grain-B concentration varied from 6.8 to 14.9 µg g^{-1}. The B control (T_1) treatment contained the lowest B concentration (6.8 µg g^{-1}). The straw-B concentration was also significantly affected due to different methods of B application ($p < 0.05$; Figure 3). The highest and lowest straw-concentrations were found by foliar spray at booting stage (15.7 µg g^{-1}) and with B control treatment (8.1 µg g^{-1}), respectively. The similar concentration was recorded with the treatment (T_5) and (T_6).

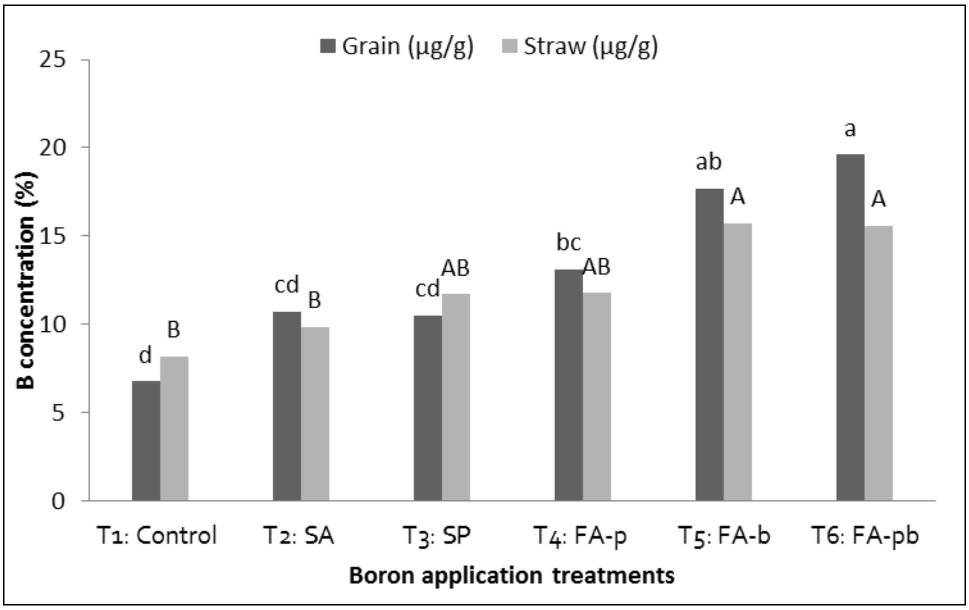

Fig. 3. Effects of different methods applicationon B concentration of wheat grain and straw. SE(±) for B in grain and straw were 3.16 and 6.29, respectively.Values in a column having same letter do not differ significantly at 5% level by DMRT

NS = Not significant

SE = Standard error of means

SA = Soil application @ 1.5 kg B ha^{-1}

SP = Seed priming with 0.1% boric acid solution for 10 hours

FA-p= Foliar spray @ 0.4% boric acid solution at primodia stage (37 DAS) of crop.

FA-b=Foliar spray @ 0.4% boric acid solution at booting stage (55 DAS) of crop.

FS-pb = Foliar spray @ 0.4% boric acid solution at primodia and booting stages of crop.

Effects of different methods of B application on the nutrient uptake by wheat

Nitrogen uptake

The N uptake by wheat grain varied due to the different B levels and methods of application ($p < 0.01$; Table 3). The N uptake by grain ranged from 46.5 to 56.09 kg ha^{-1}, the highest N uptake by grain being observed with foliar spray of B at primodia and booting stage**s** of crop (T_6) and was statistically identical with foliar spray of B at booting stage of crop (T_5) and foliar spray of B at primodia stage of crop (T_4).The lowest N uptake was observed with control treatment (T_1).Similar trend was also observed with straw(Table 3).

Phosphorus uptake

Significant effect was observed on grain P uptake of wheat ($p < 0.01$), where P uptake ranged from 8.7to14.3 kg ha^{-1} (Table 3). The highest P uptake by grain was observed with foliar spray of B at primodia and booting stage**s** (T_6) that was statistically identical with foliar spray of B at booting stage only. The lowest P uptake by grain was recorded with control treatment. The total P uptake was varied with different methods of B application (Table 3**),** being ranged from 11.0 to 15.8 kg ha^{-1}. The total P uptake was highest in foliar spray of B at primodia and booting stages (T_6) of crop, and was identical with T_5 treatment where B was sprayed on leaves at booting stage only.

Table 3. Effects of different methods ofB on N and P uptake by wheat grain and straw

Treatments	N (kg ha^{-1})			P (kg ha^{-1})		
	Grain	Straw	Total	Grain	Straw	Total
T_1: Control	46.5 b	17.1 b	63.6 b	8.70 d	2.27	11.0 c
T_2: SA	46.6 b	20.1 ab	66.8 b	11.2 c	1.29	12.5 b
T_3: SP	49.0 b	18.6 b	67.6 b	11.2c	1.30	12.5 b
T_4: FA-p	51.2ab	19.7ab	70.9ab	12.3bc	1.15	13.4 b
T_5: FA-b	51.5 ab	25.2 a	76.7 a	13.9 ab	1.35	15.2 a
T_6: FA-pb	56.09 a	18.9 b	75.0 a	14.3 a	1.49	15.8 a
Level of significance	***	**	**	**	NS	***
SE (±)	1.83	5.62	7.45	0.53	0.12	0.24

Values in a column having same letter do not differ significantly at 5% level by DMRT

* * = Significant at 1% level.

NS = Not significant, SE = Standard error of means, SA = Soil application @ 1.5 kg B ha^{-1}, SP = Seed priming with 0.1% boric acid solution for 10 hours, FA-p= Foliar spray @ 0.4% boric acid solution at primodia stage (37 DAS) of crop, FA-b=Foliar spray @ 0.4% boric acid solution at booting stage (55 DAS) of crop, FS-pb = Foliar spray @ 0.4% boric acid solution at primodia and booting stages of crop.

Potassium uptake

The K uptake by grain varied among different methods of B applications ($p < 0.01$; Table 4). The K uptake by grain varied from 9.04 to 13.1 kg ha^{-1}, where the highest K uptake by grain being recorded with foliar spray of B at primodia and booting stage of crop (T_6) that was statistically identical with the treatments T_2, T_4 and T_5.The lowest K uptake was with control treatment (T_1). On the other hand, the K uptake by straw and total K uptake (grain + straw) was significantly influenced by B application methods (Table 4). However, the K uptake by straw and total K uptake by wheat under different B treatments ranged from 72 to 101 kg ha^{-1}and 81 to 113 kg ha^{-1}, respectively. The lowest total K uptake by wheat was found in control treatment.

Sulphur uptake

The sulphur uptake by grain, straw and total grain + straw remained unaffected by B application ($p > 0.05$; Table 4). The highest grain- K uptake was found with foliar spray of B at primodia stage of crop (T_4) and the lowest K uptake found in control treatment (T_1). On the other hand, the highest and lowest straw S uptake were observed in foliar spray of B at primodia and booting stages (T_6) and control treatment (T_1), respectively. Finally, total S uptake was the highest in foliar spray of B at primodia and booting stage and the lowest was with control (T_1) treatment.

Table 4. Effect of different methods of B application on the K, S and B uptake by wheat grain and straw

B treatments	K (kg ha^{-1})			S (kg ha^{-1})			B (kg ha^{-1})		
	Grain	Straw	Total	Grain	Straw	Total	Grain	Straw	Total
T_1: Control	9.04 c	72 c	81 c	4.89	2.50	7.39	0.02 d	0.06b	0.08 b
T_2: SA	11.7ab	90ab	102	5.02	2.68	7.7	0.04c	0.05 b	0.09b
T_3: SP	10.5 bc	93 ab	103 b	5.13	2.36	7.49	0.03 cd	0.08 ab	0.11 ab
T_4: FA-p	12.0 ab	87 b	99 b	5.64	2.88	8.52	0.05 bc	0.07 ab	0.12 ab
T_5: FA-b	11.8 ab	93 b	105 b	5.06	2.83	7.89	0.06ab	0.08 ab	0.14 ab
T_6: FA-pb	13.1a	101 a	113 a	5.11	3.60	8.71	0.08a	0.11 a	0.18 a
SE (±)	0.55	16.3	11.7	1.4	1.6	2.9	0.0001	0.0002	0.001

Values in a column having same letter do not differ significantly at 5% level by DMRT.

* * = Significant at 1% level.

NS = Not significant.

SE = Standard error of means.

SA = Soil application @ 1.5 kg B ha^{-1}.

SP = Seed priming with 0.1% boric acid solution for 10 hours.

FA-p= Foliar spray @ 0.4% boric acid solution at primodia stage (37 DAS) of crop.

FA-b=Foliar spray @ 0.4% boric acid solution at booting stage (55 DAS) of crop.

FS-pb = Foliar spray @ 0.4% boric acid solution at primodia and booting stages of crop.

Boron uptake

There was a significant and positive effect of different methods of B application on the B uptake by wheat grain ($p < 0.01$; Table 4). The B uptake by grain varied from 0.02 to 0.08 kg ha^{-1}. It appeared that the foliar spray of B at primodia and booting stage**s** of crop (T_6) recorded the highest B uptake by both grain and straw that was statistically identical with foliar spray of B at booting stage of crop (T_5) in both cases. Again, in both the cases**,** the lowest B uptake was found in control treatment (T_1). Yet again, the B uptake by straw and also total B uptake (grain + straw) was not significantly influenced by the B treatments (Table 4).

Correlation among the different nutrient concentration and uptake in wheat plant

There was positive correlation among concentration (Table 5) and uptake of different nutrients by plants (Table 6). B concentration positively and significantly influenced P (r=0.85), K (r=0.75) and S content (r=0.64) of wheat plants, while B uptake had positively significantly correlated with uptake of all other nutrients. Positive correlations were also observed between nutrient concentration and nutrient uptake at harvesting stage of wheat plant (Table 5, 6 and 7). But uptake of nutrients was significantly correlated with B content in plants except N. As the correlation between B content and nutrient uptake in wheat plant was observed, it revealed that all correlation showed a strong positive relationship i.e. N (r=0.979), P(r=0.997), K (r=0.835), S (r= 0.715) and B (r= 0.939). This result indicates that the nutrient uptake in wheat may be interrupted by boron deficiency and it can be corrected by B application (Tables 5, 6 and 7).

Table 5.Correlation among concentration of different nutrientsin wheat

Concentration	N	P	K	S	B
N	1				
P	0.48	1			
K	0.49	0.55*	1		
S	0.63*	0.66*	0.77*	1	
B	0.18	0.85*	0.75*	0.64*	1

* denotes significant relationship

Table 6. Correlation among uptake of different nutrients by wheat

Correlation among different nutrient uptake					
	N	P	K	S	B
N	1				
P	0.973*	1			
K	0.755*	0.840*	1		
S	0.679*	0.747*	0.601*	1	
B	0.872*	0.935*	0.795*	0.804*	1

* denotes significant relationship.

Table 7. Correlation of different nutrient concentrations and their corresponding uptakes

	N	P	K	S	B
N	0.086	0.209	0.664*	0.062	0.103
P	0.728*	0.864*	0.924*	0.677*	0.898*
K	0.796*	0.744*	0.790*	0.368	0.537*
S	0.612*	0.637*	0.854*	0.598*	0.602*
B	0.979*	0.995*	0.839*	0.715*	0.95*

* denotes significant relationship.

Cost and return analysis

Cost and return analysis of wheat was shown in table 8.The highest gross return was obtained from T_6 whereas the lowest was from T_1. The highest cost was required in T_6 while lowest in T_1 might be due to least labour required in T_1 and B fertilizer and more labour required for premodia and booting stage.

Table 8. Cost and return analysis of wheat

Treatment	Total yield (t ha^{-1})		Gross return (Tk. ha^{-1})	Total input cost (Tk. ha^{-1})	Gross margin (Tk. ha^{-1})	BCR
	Grain	Straw				
T_1: Control	2.6	5.62	65637.5	53475.0	12161.5	1.23
T_2: SA	3.58	5.68	87340.0	56500.0	30840.0	1.55
T_3: SP	3.08	5.87	76631.0	57475.0	19156.0	1.33
T_4: FA-p	3.53	6.01	86742.5	57475.0	29267.5	1.51
T_5: FA-b	3.62	6.37	89312.5	57475.0	31837.5	1.55
T_6: FA-pb	3.63	6.39	89442.0	58375.0	31067.0	1.53

Price: Urea=17 Tk. Kg^{-1}, TSP=28 Tk. kg^{-1}, MOP=16 Tk. Kg^{-1}, Gypsum= 10 Tk. Kg^{-1}, Zinc sulphate (H_2O) = 150 Tk. Kg^{-1}, Boric acid=220 Tk. Kg^{-1}, Wheat grain=22 Tk. Kg^{-1}, Wheat straw=1.5 Tk. Kg^{-1}, Labour=250 Tk. Day^{-1} labour^{-1}, Irrigation= 1000 Tk. time^{-1} ha^{-1}

SA = Soil application @ 1.5 kg B ha^{-1}

SP = Seed priming with 0.1% boric acid solution for 10 hours

FA-p= Foliar spray @ 0.4% boric acid solution at primodia stage (37 DAS) of crop.

FA-b=Foliar spray @ 0.4% boric acid solution at booting stage (55 DAS) of crop.

FS-pb = Foliar spray @ 0.4% boric acid solution at primodia and booting stages of crop.

B. Discussion

Boron applied on wheat leaves or in soil increases nutrient uptake through increasing biomass at harvest. While boron requirement for optimum plant nutrition is low compared with those of primary nutrients, the need for boron is especially significant in branching, flowering and seed development. Schon and Blevins (1990) found increased branching; Reinbott and Blevins (1995) found increased pot setting and hence higher dry biomass yields and uptake of nutrients (Devi *et al*., 2012).According to Liebig (1955), Liebeg's Law of Minimum stated that crop used up all of the deficient nutrients in the soil making the yield directly proportional to the amount of the deficient nutrient present and the crop content of the nutrient. Growth of plants in any ecosystem is often limited by the availability of any essential nutrients irrespective of macro- or micro-nutrients. Liebig's law of the minimum stated that the nutrient in least supply relative to the plant's requirement will limit the plant's growth (Ågren *et al.*, 2012). The initial soil status showed that the soil was very low in B status. The B fertilizer applied in soil or foliar application of B helps correct the deficiency. Sakal (1991) and Devi *et al.* (2012) found B in deficiency or in excess affected the growth and yield of the soybean crop. They also put forward that B plays an important role in cell differentiation and development, translocation of photosynthates and growth regulators from source to sink and growth of pollen grains thereby marked increase in seed yield of crops. Ahmed Khan *et al*., (1990) found that dusting of 2 kg borax per hectare on sunflower heads during seed filling stage was effective in improving the seed yield by 25 %. Gormus (2005) reported significant response to foliar B treatment over the control on clay soil having 0.40 mg per kg B concentration in Adana, Turkey. Schon and Blevins (1987) at the University of Missouri demonstrated that foliar application of B could stimulate yield by increasing pod number on lateral branches, seed number, and overall seed yield. Boron is involved in the synthesis of protein (Sauchelli, 1969) and oil (Malewar *et al*., 2001). Earlier works mark the evidence that application of B influenced the yield components. Tripathy *et al*. (1999) conclusively suggested that application of B increased pod plant^{-1}. Havlin *et al*. (1999) also reported that the flowering and fruit development were restricted due to the shortage of B.

Application of B might have increased another nutrients uptake such as N, P, K and S resulting in higher biomass yield. A positive correlation observed between the B and other nutrient also proved that B application either in soil or on leaves accelerated overall nutrient uptake. Biswas *et al.* (2015) also reported similar results in a positive correlation was observed between the grain yield and the uptake of different nutrients. Boron has the favourable influence on the absorption of cations particularly calcium (Ca), to have retarding influence on the absorption of anions and to have an essential part in carbohydrate and N metabolism (Batey, 1971).This was also confirmed by Valmis and Ulrich (1971) who reported that with increasing B in the nutrient solution the concentrations of

N, P and S linearly decreased in the leaves of sugar beet. Rehim (1937), the pioneer, found that the addition of B to the nutrient medium increased the intake of cations and retarded the anions in plants as compared to culture lacking B. Bonilla *et al*. (1980) reported that both B deficiency and toxicity resulted in more NO_3-N accumulation in the sap of sugar beet due to the decrease in the activity of the N-Rase enzyme, suggesting a specific effect of B on N-Rase activity. Pollard *et al*. (1977) found that B deficiency in corn and broad beans reduced the capacity for the absorption of PO_4, due to the reduced ATPase activity, which could be rapidly restored by the addition of B. Gupta and Sanderson (1993) reported non-significant interactions between S and B in potato crop.

The increased uptake of nutrients by wheat can also be attributed to undisturbed roots for having adequate B during growing period. The B deficiency in soil can affect seedling emergence and cause an abnormal cellular development in young wheat plant (Snowball and Robson, 1983). Deficiency of B is known to inhibit the leaf expansion and reduction in photosynthesis. It also inhibits root elongation by limiting cell division in the growing zone of root tips (Dell and Huang, 1997).

Conclusions

Chemical analysis shows that the concentration of N, P, K, S and B significantly varied with the methods of B application. Foliar spray of B at primodia and booting stage recorded the highest B concentration of grain (19.6 µg g^{-1}) and reverse trend was observed with control treatment(T_1).Positive correlation was found with P. N concentration resulted in more protein synthesis. It also appeared that the foliar spray of B at primodia and booting stage recorded the highest B uptake with both grain and straw but statistically no difference was with the foliar spray at booting stage (T_5). The uptake of various nutrients by the crop showed the positive trend of wheat yield. T_5 treatment gave the highest gross margin though it input its input cost was less than T_6 treatment.

Acknowledgements

The authors gratefully acknowledged the financial support provided by the USDA through the project "Screening, selection and molecular characterization of boron efficient wheat genotypes" to carry out this work.

References

Ågren, G.I., A.M. Wetterstedt, M.F.K. Billberger. 2012. Nutrient limitation on terrestrial plant growth – modeling the interaction between nitrogen and phosphorus. *New Phytologist.* **194:** 953–960.

Ahmad, W., M.H. Zia, S.S. Malhi, A. Niaz and Saifullah. 2012. Boron Deficiency in Soils and Crops: A Review. *In:* Aakash, G. (editor), *Crop plant.* Shanghai, China: InTech. 77-114.

Ahmed, K.T., K. Venugopal, C. Devaih and K. Seenapa 1990. Effect of secondary nutrients and boron on growth characters and yield in sunflower. *J. Oilseeds Res.* **7:** 136-139.

Ahmed, M.U., M. Jahiruddin, M.S. Hoque, M.M. Rahman and M.J. Abedin. 1991. Response of wheat (*Triticuma estivum*) to sulphur, zinc and boron in Old Brahmaputra Flood plain soil. *Bangladesh J. Crop Sci*. **2**(2): 91-98.

Batey, T. 1971. Manganese and boron deficiency. Trace elements in soils and crops. Technical Bulletin, 21. Her Majesty's Stationary Office, London, Pp: 137-148.

Bhatta, M.R. and G.O. Ferrara. 2005. Wheat sterility induced by boron deficiency in Nepal. In: Micronutrients in South and South East Asia, 221-229. P. Andersen, J. K. Tuladhar, K.B. Karki and Maskey, S.L. (Eds), International Centre for Integrated Mountain Development (ICIMOD), Kathmandu, Nepal.

Bonilla, I., O. Cadahia, O. Carpena and V. Hernando. 1980. Effects of boron on nitrogen metabolism and sugar levels of sugar beet. *Plant Soil*. **57:** 3-9.

Biswas, A., D. Mukhopadhyay and A. Biswas. 2015. Effect of soil zinc and boron on the yield and uptake of wheat in an acid soil of West Bengal, India. *International J. Plant & Soil Science*. **6**(4): 203-217, 2015.

Chakraborti, S.K. and P. Barman. 2003. Enhancement of yield of wheat genotypes by application of borax in Terai region. *J. Interacademicia.* **7:** 256-261.

Chaudhry, E.H., V. Timmer, A. S. Javed and M.T. Siddique. 2007. Wheat response to micronutrients in rain-fed areas of Punjab. *Soil & Environment.* **26:** 97-101.

Cooke, G.W. 1982. Fertilizing for Maximum Yield. Granada, UK, 465 P.

Dell, B., and L.B. Huang. 1997. Physiological response of plants to low boron. *Plant Soil.* **193:**103-120.

Devi K.N., L.N.K. Singh, M.S. Singh and S.B. Singh 2012. Influence of sulphur and boron fertilization on yield, quality, nutrient uptake and economics of Soybean (*Glycine max*) under upland conditions. *J. Agric. Sci.* **4**(4): 1-10.

Gomez, K.A. and A.A. Gomez. 1984. Statistical Procedures for Agricultural Research. 2nd ed. NewYork: Wiley, Pp: 188–206.

Gorums, O. 2005. Interactive effect of nitrogen and boron on cotton yield and fiber quality. *Turkish Journal of Agriculture and Forestry*. **29:**51-59.

Gupta, U.C. and J.B. Sanderson. 1993. Effect of sulfur, calcium, and boron on tissue nutrient concentration and potato yield. *J. Plant Nutrition.* **16:** 1013-1023.

Haque, M.A., M. Jahiruddin and M.R. Islam. 2000. Effect of sulphur and boron on seed yield of mustard (*Brassica napus*). *Bangladesh J. Seed Sci. and Tech.* **4**(1&2): 7-11.

Havlin, L.J., D.J. Beaton, L.S. Tisdale and L.W. Nelson. 1999. Soil fertility and fertilizers. *Prentice Hall of Indian*. 6th ed., Pp: 220, 227, 228, 319-346.

Jahiruddin, M., M. S. Ali, M. A. Hossain, M. U. Ahmed, and M. M. Haque. 1995. Effect of boron on grain set, yield and some other parameters of wheat cultivers. *Bangladesh J. Agril. Sci.* **22**(1): 179-184.

Liebig, J. 1955. DieGrundsa¨tze der Agrikultur-ChemiemitRu¨cksicht auf die in England angestelltenUntersuchungen, 1st and 2nd edn. Braunschweig, Germany: Friedrich Vieweg und SohnPubl Co.

Mahler, R.L. 2010. Boron in Idaho. In: Essential Plant Nutrient, College of Agriculture. Cooperative Extension System. CIS 1085.

Malewar, G.V., S.D. Kate, S.L. Walker and S. Ismail. 2001. Interaction effect of zinc and boron on yield, nutrient uptake and quality of mustard *(Brassica juncea*L.) on a TypicHaplustert. *J. Indian Soc. Soil Sci.,* **49:** 763-765.

Marphy, L.S. and L.M. Walsh. 1972. Correction of micronutrient deficiencies with fertilizers. Soil Sci. Amer., Inc., Madi., Wis., USA.

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

Niaz, A., A.M. Ranjha, Rahmatullah, A. Hannan and M. Waqas. 2007. Boron status of soils as affected by different soil characteristics–pH, CaCO3, organic matter and clay contents. *Pakistan J. Agril. Scien.* **44:** 428-435.

Pollard, A.S., A.J. Parr and B.C. Loughman. 1977. Boron in relation to membrane function in higher plants. J. Exp. Bot., **28:** 831-841.

Rehim, S. 1937. The effect of boric acid on the growth and salt intake of impatientsbalsamina. *JahrabWiss. Bot.* **85:** 788-814.

Reinbott, T.M. and D.G. Blevins. 1995. Response of soybean to foliar applied boron and magnesium and soil applied boron. *J. Plant Nutr*. **18:**179-200.

Rerkasem, B., S. Jamjod. 2004. Boron deficiency in wheat: a review. Field Crops Research. **89:** 173–186

Sakal, R. 1991. Relative susceptibility of some important varieties of sesamum and mustard to boron deficiency in calcareous soil. Fertilizer News, **36:**43-46.

Sauchelli, V. 1969. Trace element in Agriculture. *Van Nostrand*. Reinhold Company, New York, Pp: 84-87-88.

Schon, M.K. and D.G. Blevins. 1987. Boron stem infusions stimulate soybean yield by increasing pods on lateral branches. *Plant Physiol*., **84:**969-71.

Schon, M.K. and D.G. Blevins. 1990. Foliar boron applications increase the final number of branches and pods on branches of field grown soybeans. *Plant Physiol*. **92:**602-607.

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

Snowball, K. and A.D. Robson. 1983. Symptoms of nutrient deficiencies: Subterranean clover and wheat. Institute of Agriculture, University of Western Australia: Nedlands, Western Australia.

Soylu, S. and A. Topal. 2004. Yield and yield attributes of durum wheat genotypes as affected by boron application in boron-deficient calcareous soils: an evaluation of major Turkish genotypes for boron efficiency. *Journal of Plant Nutrition.* **27:** 1077-1106.

Tripathy, S.K., A.K. Patra and S.C. Samui. 1999. Effect of micronutrient on nodulation, growth, yield and nutrient uptake by groundnut (*Arachishypogaea*). *Indian J. Plant Physiology*. **4:**207-209.

Valmis, J. and A. Ulrich. 1971. Boron nutrition in the growth and sugar content of sugar beets. *J. Am. Soc. Sugarbeet Technol.* **16:** 428-439.