Science Letters
2016 | Volume 4 | Issue 1 | Pages 44-50

RESEARCH ARTICLE OPEN ACCESS

Improving the Productivity of Bt Cotton (*Gossypium hirsutum* L.) Through Integrated Plant Nutrient Management

Maqshoof Ahmad[1*], Moazzam Jamil[1], Zubair Ahmad[1], Muhammad Ali Kharal[1], Abid Niaz[2], Muhammad Iqbal[1], Muhammad Fakhar-u-Zaman Akhtar[1], Muhammad Latif[1]

[1]University College of Agriculture and Environmental Sciences, The Islamia University of Bahawalpur, Bahawalpur, Pakistan
[2]Soil Chemistry Section, Institute of Soil Chemistry and Environmental Sciences, AARI, Faisalabad, Pakistan

Abstract
Cotton is an important cash crop of Pakistan and it is very popular among the farmers' community of southern Punjab, especially the Bahawalpur area. According to National data, both zinc and boron are more deficient micronutrients in the soils of Pakistan. Farmers apply fertilizers in haphazard manners without any recommendation and they have very little know-how about the role of micronutrients, especially boron and zinc on cotton (*Gossypium hirsutum* L.). A field experiment was conducted to determine the response of cotton to boron and zinc applications along with NPK in the soils of southern Punjab to increase the quality, growth and yield of cotton. The results showed that the integrated use of micro and macronutrients caused a significant improvement in growth, yield, nutrient uptake and fiber quality of the cotton crop. Maximum improvement in plant height (61%), boll diameter (75%), number of bolls plant^{-1} (100%), and fiber strength (11%) was observed in T8 where boron @ 2 kg ha^{-1} and zinc @ 5 kg ha^{-1} were applied along with recommended dose of NPK. The T8 also significantly improved the nutritional status (51, 75, 40%, 94%, and 72% increase in N, P, K, Zn and B contents) and yield of cotton (44% and 48% increase in lint yield and cotton seed yield, respectively) as compared to unfertilized control. It is concluded that boron @ 2 kg ha^{-1} and zinc @ 5 kg ha^{-1} should also be applied in combination with macronutrients for sustainable production of Bt cotton.
Keyword Bt-cotton, fiber quality, integrated, productivity, growth, nutrient, management.

Received October 30, 2015 **Accepted** January 15, 2016 **Published** April 15, 2016
***Corresponding author** Maqshoof Ahmad **E-mail** maqshoof_ahmad@yahoo.com

To cite this manuscript: Ahmad M, Jamil M, Ahmad Z, Kharal MA, Niaz A, Iqbal M, Akhtar MFZ, Latif M. Improving the productivity of Bt cotton (*Gossypium hirsutum* L.) through integrated plant nutrient management. Sci Lett 2016; 4(1):44-50.

Introduction

Pakistan is the fourth largest producer of cotton (*Gossypium hirsutum* L.) in the world and is a vital player in the cotton producing countries. Cotton covers about 3 million hectare area and shares about 1.5% of GDP annually [1]. It fulfills the demand of raw lint for country's largest industry (Textile industry) and makes a good affluence in the form of foreign exchange [2]. However, the yield of cotton in Pakistan is still far behind from developed countries. Judicious use of fertilizers is a key to obtaining maximum yield in all crops, including cotton [3]. Cotton plant has an indeterminate growth pattern, so the use of balanced micro and macro nutrients is essential for the optimum vegetative and reproductive growth to obtain maximum yield [4]. For Bt-cotton, a lot of work has been done in developing optimum levels of NPK fertilizers, but there is a lack of interest in determining the adequate levels of micro-nutrients for its sustainable production. While, under our soil conditions, boron and zinc are reported as deficient micronutrient and their deficiency significantly lowering cotton yield in the recent years [5]. For the nutrition of the cotton plant, boron is considered as a crucial component. Its deficiency results in alteration of many physiological processes and if applied in excess, its toxicity results in a severe reduction in yield [6]. Boron holds key tasks in cotton's vegetative as well as reproductive growth. During early development, it is involved in cell growth and elongation, by regulating the translocation of sugars, formation of cell wall, mediating the synthesis of amino acids and carrying out the nitrate metabolism [7, 8]. At later stages, boron is involved in flowering, seed and fruit development. Goldbach [9] reported that boron is involved in facilitating the uptake and utilization of phosphorus by controlling phosphorus efflux during root and flower growth. It is also involved in the pollen growth and fertilization, by maintaining the hormonal concentrations in ovary, ensuring better seed growth and fiber quality [10]. On the other hands, the excessive supply of boron results in severe toxicity leading to necrotic leaves and lowering the dry matter production [6]. The higher concentration of boron results in deficiency of Ca^{+2} and K^{+} resulting in browning of leaves and death of terminal bud [11]. Higher level of boron also fixes the NAD^{+} and ribose sugars in cytoplasm, resulting in inhibition of RNA activity leading to the restricted biosynthesis of several enzymes involved in plant biochemical machinery [12, 13]

Alkaline calcareous soils of arid and semi-arid regions in the whole world are the main cause of zinc deficiency in plant nutrition and ultimately in the plants [14]. Zinc availability lowers down due to the precipitation of zinc in alkaline soil solution, and due to the fixation of zinc with $CaCO_3$ particles and mainly due to lower zinc replacement in soil solution because of low organic matter contents generally less than 1% [14]. Zinc plays an important role as a catalyst in many enzymatic metabolic processes [15], like the integrity of membrane [16], protein compounds synthesis, biosynthesis of tryptophan [17], nitrogen, phosphorus and potassium uptake by plants and their metabolism and mobilization of photosynthates [18, 19]. In the plants grown in zinc deficient soils, the plant leads to punctured plasma membrane in mostly plant roots as observed by high rates of efflux of K^+ [16, 19]. Keeping in view the importance of boron and zinc in plant nutrition and the consequences of their mismanagement, the present study was conducted to determine the adequate level of boron along with other micro and macro nutrients for sustainable production of Bt cotton.

Materials and methods

Field experiment

A field experiment was conducted to determine the adequate level of boron and zinc for quality production of cotton. The experiment was laid out in Randomized Complete Block Design with four replications. A set of treatments as T_1 = Control (No fertilizer), T_2 = NPK (230-80-65 kg ha^{-1}), T_3 = Boron (1 kg ha^{-1}), T_4 = Boron (2 kg ha^{-1}), T_5 = Boron (3 kg ha^{-1}), T_6 = Zinc (5 kg ha^{-1}), T_7 = Boron (1 kg ha^{-1}) and zinc (5 kg ha^{-1}), T_8 = Boron (2 kg ha^{-1}) and zinc (5 kg ha^{-1}) and T_9 = Boron (3 kg ha^{-1}) and zinc (5 kg ha^{-1}) was used in the experiment. The recommended dose of NPK fertilizer was applied to all plots except control.

For the sowing of crop, land was prepared at proper filed capacity, once with mould board plough and harrowed twice to bring the soil to a fine tilth. S-Metolachlor was applied as pre-emergence herbicide and paraquat for eradication of growing weeds. The NPK were applied as urea, diammonium phosphate and sulfate of potash, respectively. The entire dose of P and K were applied as basal dose during land preparation, while N was applied in four splits. The boron and zinc were applied as Borax and $ZnSO_4$, respectively. Whole dose of zinc was applied at the time of 1st irrigation as soil application while boron was applied in two splits as foliar spray. Adequate irrigation was provided to the experimental area for minimizing effect of drought stress during cotton growth stages, especially at the reproductive stage. The field remained in observation throughout the course of experiment to avoid the unseen damages. Insects were monitored throughout the experiment and no insect control was found necessary during the growing season. During the experiment, ten plants were selected randomly for observations in each plot. All physiological traits were measured 80 days after planting, the time of peak flowering and fruiting. After all bolls had opened, a total of 50-boll sample was collected from each plot by hand-harvesting for boll weight, seed cotton weight per boll and number of seeds per boll. Plots were harvested twice by hand and yield of four rows of the plot was weighed and calculated for seed cotton yield. The first harvest was done on 15 October, 2013 and the second harvest was made on 11 November, 2013. The samples were ginned on a laboratory roller gin, and seed samples of 100 seeds were taken from each of the replicates of field plots for 100 seed weight. For measuring staple length, fiber strength and fiber fineness, a sample of 40 g lint with 8% moisture was taken from each family in each replication, and tested using HVI (High Volume Instrument).

Plant analysis

The plant sample digestion was done according to the Wolf [20] and nitrogen contents were determined using micro kjheldahl apparatus as described by Ryan et al. [21]. Phosphorus and potassium were determined using spectrophotometer and flame photometer, respectively, according to the method of Chapman and Prat [22] and Ryan et al. [21], respectively. Zinc and boron were determined by atomic absorption spectrometer as described by Ryan et al. [21].

Statistical analysis

The collected data were analyzed by using Fisher's analysis of variance technique and LSD at 5% probability was used to compare the treatment means [23].

Results

Effect of different levels of boron and zinc on growth attributes of Bt-cotton

The data regarding the effect of different levels of boron and zinc on growth attributes of Bt-cotton (Table 1) indicates that minimum plant height was observed in control and the application of recommended dose of NPK fertilizer (T_2) resulted in a significant increase (33%) in plant height. While, the application of boron @ 1, 2 and 3 kg ha^{-1} along with recommended dose of NPK (T_3, T_4 and T_5) resulted in 39.48%, 48.35% and 54.02% increase in plant height, respectively compared to control (T_1). The application of different doses of boron, along with zinc (5 kg ha^{-1}) resulted in significantly higher increase in plant height compared to T_1 (control), T_2 (NPK 230-80-65 kg ha^{-1}), T_3 (boron 1 kg ha^{-1}), T_4 (boron 2 kg ha^{-1}) and T_5 (boron 3 kg ha^{-1}).

The results regarding the number of sympodial branches plant^{-1} (Table 1) indicated that the lowest number of sympodial branches plant^{-1} (10.33 plant^{-1}) were observed in control (T_1), while with the application of recommended NPK, boron and zinc resulted in a significant increase in the number of sympodial branches plant^{-1} (up to 1 fold). Though, the maximum increase in the number of sympodial branches plant^{-1} was observed when recommended NPK, zinc and boron were applied together. However, no significant difference was observed with increasing concentration of boron among T_7 (Boron 1 kg ha^{-1} and zinc 5 kg ha^{-1}), T_8 (Boron 2 kg ha^{-1} and zinc 5 kg ha^{-1}) and T_9 (Boron @ 3 kg ha^{-1} and zinc @ 5 kg ha^{-1}).

Effect of different levels of boron and zinc on yield attributes of Bt-cotton

The results regarding the yield parameters revealed (Table 1) that the application of NPK and different levels of boron (1 kg ha^{-1}, 2 kg ha^{-1} and 3 kg ha^{-1}), separately and along with zinc @ 5 kg ha^{-1}, resulted in a significant increase in boll diameter and number of bolls plant^{-1}. The data showed that the maximum boll diameter and the number of bolls plant^{-1} were observed in T_9 (boron 3 kg ha^{-1} and zinc 5 kg ha^{-1} and T_8 (boron 2 kg ha^{-1} and zinc 5 kg ha^{-1} followed by T_5 (boron 3 kg ha^{-1}).

The data presented in Fig. 1 also showed that the application of boron and zinc with NPK resulted in a significant increase in seed cotton yield. The results showed that the application of NPK, boron 3 kg ha^{-1} and zinc 5 kg ha^{-1} (T_9) resulted in the maximum increase (83.6%) in seed cotton yield as compared to control. However, no significant difference was observed with increasing boron levels. Moreover, when zinc was not applied with boron, the seed cotton yield was significantly lower than T_9 (boron 3 kg ha^{-1} and zinc 5 kg ha^{-1}).

The data regarding lint yield (Fig. 2) showed that the sole application of boron (1, 2 and 3 kg ha^{-1}) along with NPK (T_3, T_4 and T_5) resulted in a significant increase in lint yield (33.5%, 41.7% and 44.8%, respectively). Furthermore, the application of NPK, boron 3 kg ha^{-1} and zinc 5 kg ha^{-1} (T_9) showed a maximum increase (1 fold) in the lint yield followed by T_8 (boron 2 kg ha^{-1} and zinc 5 kg ha^{-1}).

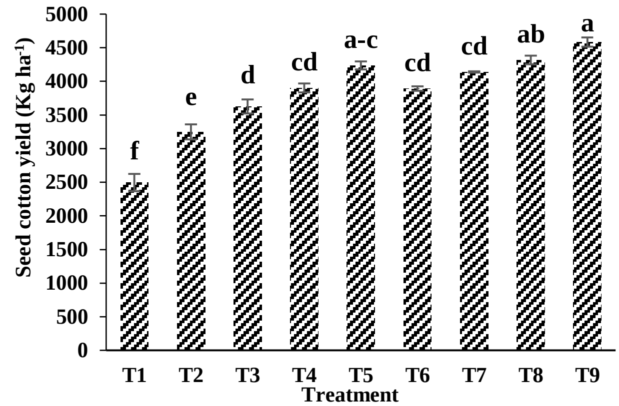

Fig. 1 Effect of different doses of macro and micronutrients on the seed yield of cotton (Bars sharing same letters are statistically show non-significant results at par at the 5 % level of probability).

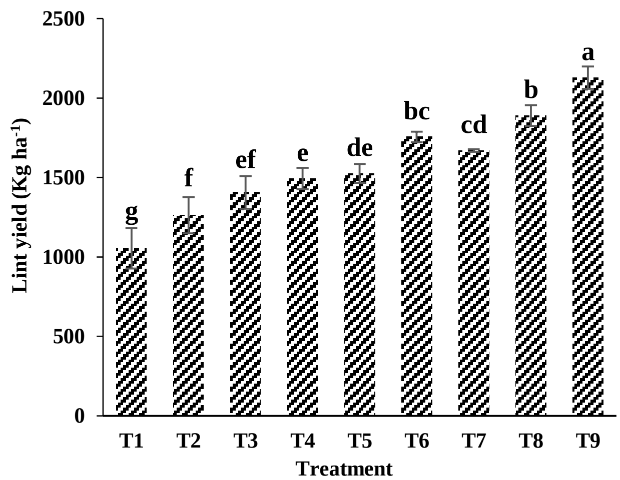

Fig. 2 Effect of different doses of macro and micronutrients on lint yield of cotton (Bars sharing same letters are statistically show non-significant results at par at the 5 % level of probability).

Effect of different levels of boron and zinc on lint quality of Bt-cotton

The data (Table 2) showed that the spinning consistency index (SCI) of cotton fiber was significantly increased with the application of macro (NPK) and micronutrients (zinc and boron), as compared to control. The application of NPK, boron 1 kg ha^{-1} and zinc 5 kg ha^{-1} (T_7) resulted in the maximum increase (14%) in SCI. Moreover, all other treatments showed higher SCI as compared to control but there was no statistical difference among them.

Table 1 Effect of different doses of macro and micronutrients on the growth and yield parameters of Bt-cotton.

Treatment (kg ha^{-1})	Plant height (cm)	No. of Sympodial branches (plant^{-1})	Boll diameter (cm)	No. of bolls plant^{-1})
Control	117.60 ± 2.193 f	10.33 ± 0.600 e	2.34 ± 0.128 f	31.00 ± 1.323 f
RD NPK only (230-80-65)	156.03 ± 1.675 e	17.00 ± 0.289 d	2.71 ± 0.019 e	56.33 ± 1.301 e
Boron (1 kg ha^{-1})	164.63 ± 1.129 d	18.67 ± 0.440 c	2.99 ± 0.147 e	59.57 ± 0.928 e
Boron (2 kg ha^{-1})	174.47 ± 2.511 c	18.77 ± 0.145 c	3.46 ± 0.187 d	64.33 ± 1.878 d
Boron (3 kg ha^{-1})	181.13 ± 0.897 b	20.00 ± 0.289 b	3.94 ± 0.027 bc	71.00 ± 1.041 bc
Zinc (5 kg ha^{-1})	189.53 ± 0.926 a	20.00 ± 0.289 b	3.42 ± 0.083 d	65.50 ± 2.309 d
Boron + Zinc (1 + 5 kg ha^{-1})	188.13 ± 1.980 a	21.17 ± 0.440 ab	3.68 ± 0.056 cd	67.17 ± 1.220 cd
Boron + Zinc (2 + 5 kg ha^{-1})	189.77 ± 2.890 a	21.33 ± 0.440 a	4.10 ± 0.091 ab	73.00 ± 0.764 ab
Boron + Zinc (3 + 5 kg ha^{-1})	191.03 ± 0.987 a	21.50 ± 0.288 a	4.37 ± 0.083 a	85.67 ± 0.928 a
LSD ($p \leq 0.05$)	5.44	1.18	0.32	4.06

RD = recommended dose; Means sharing same letters are statistically show non-significant results at par at 5 % level of probability.

Table 2 Effect of different doses of macro and micronutrients on the fiber quality of Bt-cotton.

Treatment (kg ha^{-1})	Spinning consistency index (SCI)	Fiber fineness (Micronaire)	Upper half mean length	Fiber strength (kN-m kg^{-1})
Control	129.33 ± 1.86 c	4.24 ± 0.23 c	1.12 ± 0.02 a	28.73 ± 0.786 cd
RD NPK only (230-80-65)	142.33 ± 0.33 ab	4.61 ± 0.04 ab	1.14 ± 0.01 a	29.43 ± 0.09 bc
Boron (1 kg ha^{-1})	139.33 ± 0.88 ac	4.57 ± 0.02 ab	1.13 ± 0.00 a	29.93 ± 0.03 bc
Boron (2 kg ha^{-1})	136.33 ± 1.20 ac	4.63 ± 0.04 ab	1.13 ± 0.01 a	26.60 ± 0.10 d
Boron (3 kg ha^{-1})	141.67 ± 0.88 ac	4.40 ± 0.07 bc	1.12 ± 0.03 a	29.13 ± 0.50 bd
Zinc (5 kg ha^{-1})	143.67 ± 1.86 ab	4.73 ± 0.13 a	1.12 ± 0.02 a	31.51 ± 0.90 ab
Boron + Zinc (1 + 5 kg ha^{-1})	147.33 ± 5.21 a	4.74 ± 0.047 a	1.15 ± 0.00 a	30.80 ± 2.18 ac
Boron + Zinc (2 + 5 kg ha^{-1})	142.00 ± 10.02 ab	4.22 ± 0.07 c	1.11 ± 0.02 a	32.75 ± 0.71 a
Boron + Zinc (3 + 5 kg ha^{-1})	134.00 ± 1.00 bc	4.66 ± 0.07 ab	1.13 ± 0.01 a	28.33 ± 0.23 cd
LSD ($p \leq 0.05$)	12.41	0.31	0.04	2.68

RD = recommended dose; Means sharing same letters are statistically show non-significant results at par at 5 % level of probability.

The data presented in Table 2 showed that T_6 (zinc 5 kg ha^{-1}) and T_7 (boron 1 kg ha^{-1} and zinc 5 kg ha^{-1}) showed a maximum increase in fiber fineness i.e. 11.8% increase in each case. Additionally, the results also showed that the upper half mean length (UHML) of cotton fiber was unaffected by the application of zinc and boron as no significant difference among the treatments was observed regarding UHML. The results regarding fiber strength described that the maximum fiber strength (32.75 kN-m kg^{-1}) was observed in T_8 (boron 2 kg ha^{-1} and zinc 5 kg ha^{-1}) followed by T_6 (zinc 5 kg ha^{-1}) and T_7 (boron 1 kg ha^{-1} and zinc 5 kg ha^{-1}). The statistical analysis of data indicated that T_6, T_7 and T_8 were not significantly different from each other.

Effect of different levels of boron and zinc on nutrient concentration in shoots of Bt-cotton

The data regarding nutritional analysis (Table 3) showed that the application of macro and micronutrient in different combinations resulted in a significant increase in nitrogen, phosphorus and potassium concentration in shoots. The results showed that the maximum increase in nitrogen (53.2%) and phosphorus (91%) was resulted in T_9 (boron 3 kg ha^{-1} and zinc 5 kg ha^{-1}), while in the case of potassium, the maximum increase (47.7%) was observed in T_7 (boron 1 kg ha^{-1} and zinc 5 kg ha^{-1}).

Similarly, in the case of zinc and boron, the data showed (Table 3) that the application of boron in combination with zinc and NPK resulted in a significant increase in zinc concentration in shoots of Bt-cotton. The maximum increase in zinc resulted in T_9 (boron 3 kg ha^{-1} and zinc 5 kg ha^{-1}) and T_8 (boron 2 kg ha^{-1} and zinc 5 kg ha^{-1}), which were statistically similar (97.32% and 94.68% increase, respectively). It was also evident from the results (Table 3) that boron concentration was significantly increased with increasing boron level as the maximum increase in boron concentration in shoots (1 fold) was observed in T_9 where 3 kg ha^{-1} boron was applied with NPK and 5 kg ha^{-1} zinc.

Discussion

Our study results clearly revealed that the combined use of recommended NPK, boron and zinc significantly improved the crop yield and quality. Several previous studies had determined the positive effect of boron and zinc along with NPK fertilizers on growth, yield, lint quality and nutrient uptake of Bt-cotton [24-28]. The sufficient supply of micro and macronutrients results in efficient hormonal activity. Higher uptake of boron and zinc promote the synthesis of growth promoting hormones, especially the production of auxins resulting in enhanced growth and increased the number of internodes that

Table 3 Effect of different doses of macro and micronutrients on nutrient concentration in shoots of Bt-cotton.

Treatment	Nitrogen (%)	Phosphorus (%)	Potassium (%)	Zinc (μg g^{-1})	Boron (μg g^{-1})
Control	3.61 ± 0.02 g	0.33 ± 0.01 d	3.27 ± 0.09 e	25.00±1.53 df	27.0 ±1.16 e
RD NPK only (230-80-65)	4.89 ± 0.01 f	0.57 ± 0.01 b	4.23 ± 0.03 d	24.33±0.67 f	26.67±0.88 e
Boron (1 kg ha^{-1})	4.92 ± 0.01 f	0.53±0.01 c	4.33 ± 0.07 cd	24.67±0.88 de	37.33±0.67 c
Boron (2 kg ha^{-1})	5.37 ± 0.02 d	0.57 ± 0.01 b	4.60 ± 0.06 b	25.33±0.88 de	36.00 ± 0.58 c
Boron (3 kg ha^{-1})	5.44 ± 0.02 bc	0.55 ± 0.01 b	4.59 ± 0.033 b	27.00±0.58 d	46.00 ± 1.15 b
Zinc (5 kg ha^{-1})	5.15 ± 0.01 e	0.53 ± 0.01 c	4.70 ± 0.06 ab	48.33±0.67 ab	27.67 ± 0.88 e
Boron + Zinc (1 + 5 kg ha^{-1})	5.42 ± 0.01 c	0.52 ± 0.01 c	4.83 ± 0.03 a	46.33±0.67 b	34.33 ± 0.67 d
Boron + Zinc (2 + 5 kg ha^{-1})	5.47 ± 0.01 b	0.58 ± 0.01 b	4.60 ± 0.06 b	48.67 ± 0.33 ab	46.67 ± 0.88 b
Boron + Zinc (3 + 5 kg ha^{-1})	5.53 ± 0.01 a	0.63 ± 0.01 a	4.43 ± 0.03 c	49.33 ± 0.88 a	56.00 ± 0.58 a
LSD ($p \leq 0.05$)	0.0416	0.0245	0.1508	2.5396	2.6017

RD = recommended dose; Means sharing same letters are statistically show non-significant results at par at 5 % level of probability.

promoted the development of main shoot as well growth of sympodial branches [29-33]. Blevins and Lukaszewski [7] explained that the boron plays a pivotal role in nitrogen metabolism, membranes functioning, photosynthesis and cell division. The application of boron improved all these physiological processes, resulting in improved growth due to enhanced protein synthesis and efficient supply of metabolites [34]. All these factors are collectively responsible of increased growth attributes as shown in Table 1. Kausar et al. [35] and Ahmad et al. [27] reported that the balanced use of macro and micronutrients resulted in a significant increase in yield and product quality. Lint quality is adversely affected by the boron deficiency as it has a primary role in regulating lint quality and boll development. The deficiency of zinc is also a well-documented issue that decreases the crop yields by significantly decreasing plant performance [36, 37]. Since, these micronutrients are involved in indispensable functions like translocation and incorporation of sugar compounds and nitrogen in complex carbohydrates (fiber) and proteins.

The need of zinc and boron are highest during seed formation and lint development. However, under calcareous soil conditions, there is acute shortage of these nutrients which results in the lower yield and lint quality, which could only be overcome by the application of these nutrients along with NPK fertilization [38]. Wójcik et al. [39] reported that boron and zinc application improved the transport and deposition of assimilates in fruiting body resulting in enhanced fruit yield and quality. The increased yield also attributed to the increased boronic acid mediated carbohydrate transport through cell membranes [10, 40]. Zinc has a synergistic relationship with most of essential nutrients especially nitrogen. The integrated use of zinc along with other nutrients enhanced its uptake [41]. Boron and zinc fertilization also significantly improved phosphorus accumulation in seeds that enhance the protein contents resulting in the higher seed yield as reported by Aref [42].

In our study, the nutritional analysis of cotton plants showed that the use of boron and zinc with NPK resulted in significantly higher uptake of nitrogen, phosphorus, potassium zinc and boron. Siddiqui et al. [43] reported similar results as they concluded that the use of 1.5 kg ha^{-1} boron with recommended NPK and zinc resulted in maximum improvement in the nutrient status of the plant. Similar results were also reported by Neena and Chatterjee [44] which further strengthened our findings. Marschner [45] suggested that boron is a key element of several enzymes involved in the regulation of nutrients, metabolites transfer and cell membrane permeability. Zinc is also known to have an important role in nutrients uptake and metabolism. In addition, hormonal regulation and photosynthates transportation are also regulated by boron [17-19]. Several previous studies clarified the role of boron and zinc in nutrients transport and uptake in the plant's body as Robertson and Loughman [46] and Parr and Loughman [47] proposed that the deficiency of boron limit the uptake of nutrients in plant body and inhibit the activity of enzymes involved in the long distance transfer of nutrients in plants. The inhibited activity of enzymes may be attributed to the lower activity of ATPase in membrane vessels under limited supply of phosphorus due to zinc deficiency [48]. The adequate supply of boron and zinc result in improved plant's internal physiology and improved nutrient uptake and assimilation [49-51].

Conclusions

This study revealed that judicious and balanced use of micro and macronutrients in Bt-cotton substantially improved the growth, boll diameter, number of bolls per plant, fiber quality, nutrient uptake and seed cotton yield. The results also showed that the combination of boron and zinc (2 kg ha^{-1} and 5 kg ha^{-1}, respectively) along with recommended

NPK significantly increased the yield and quality of cotton than their applications alone.

References

[1] Aslam M, Sanghi AH, Javed S, Khalid L. Effect of sowing time on yield and yield components of wheat sown in standing cotton. J Agric Res 2013; 51:133-140.

[2] Ahmed AUH, Ali R, Zamir SI, Mehmood N. Growth yield and quality performance of cotton cultivar BH-160 (*Gossypium hirsutum* L.). J Anim Plant Sci 2009; 19:189-192.

[3] Ahmad N. Fertilizer scenario in Pakistan policies and development. In: Proceedings of Conference Agricultural and Fertilizer Use. NFDC, P and D Division, Government of Pakistan, February 15-16. 2000.

[4] Sawan ZM, Mahmoud MH, El Guibali AH. Response of yield, yield components, and fiber properties of Egyptian cotton (*Gossypium barbadense* L.) to nitrogen fertilization and foliar-applied potassium and mepiquat chloride. J Cotton Sci 2006; 10: 224–234.

[5] Shah JA, Zia-ul-hassan, Rajpar I, Sial. MA. Evaluating boron-use-efficiency of twenty cotton genotypes of Pakistan. Pak J Agric Agric Eng Vet Sci 2014; 30:147-158

[6] Ahmed N, Abid M, Ahmad F. Boron toxicity in irrigated cotton (*Gossypium hirsutum* L.). Pak J Bot 2008; 40:2443-2452.

[7] Blevins DG, Lukaszewski KM. Boron in plant structure and function. Ann Rev Plant Physiol Plant Mol Biol 1998; 49:481–500.

[8] Zhao D, Oosterhuis DM. Cotton growth and physiological responses to boron deficiency. J Plant Nutr 2003; 26:855-867.

[9] Goldbach HE. Infuence of boron nutrition on net uptake and eflux of 32P and 14C-glucose in *Helianthus annuus* roots and cell cultures of *Daucus carota*. J Plant Physiol 1984; 118:431–438.

[10] Brown PH, Bellaloui N, Wimmer MA, Bassil ES, Ruiz J, Hu H, et al. Boron in plant biology. Plant Biol 2002; 4:205-223.

[11] Reid RJ, Hayes JE, Post A, Stangoulis JCR, Graham RD. 2004. A critical analysis of the causes of boron toxicity in plants. Plant Cell Environ 2004; 25:1405-1414.

[12] Loomis WD, Durst RW. Chemistry and biology of boron. BioFactors 1992; 3:229-239.

[13] Sotiropoulos TE, Therios NI, Dimassi NK, Bosbalidis A, Kofilids G. Nutritional status, growth, CO_2 assimilation and leaf anatomical responses in two kiwi fruit species under boron toxicity. J Plant Nutri 2002;5:1244-1261

[14] Rashid A, Ryan J. Micronutrient constraints to crop production in soils with Mediterranean-type characteristics: a review. J Plant Nutri 2004; 27:959-975.

[15] Vallee BL, Auld DS. Zinc coordination function and structure of zinc enzymes and other proteins. Biochem 1990; 29:5647–5659.

[16] Cakmak I, Marschne H. Increase in membrane permeability and exudation of roots of zinc deficient plants. J Plant Physiol 1988; 132:356-361.

[17] Oosterhuis DM, Hake K, Burmester C. Foliar feeding cotton. Cotton Physiology Today. National Cotton Council of America 1991; 2:1–7.

[18] Glass ADM. Plant nutrition an introduction to current concepts. Jones and Bartlett Publishers, Boston/Portola Valle; 1989.

[19] Li DD, Tai FJ, Zhang ZT, Li Y, Zheng Y, Wu YF, et al. 2009. A cotton gene encodes a tonoplast aquaporin that is involved in cell tolerance to cold stress. Gene 2009; 438:26–32.

[20] Wolf B. The comprehensive system of leaf analysis and its use for diagnosing crop nutrient status. Comm Soil Sci Plant Anal 1982; 13:1035-1059.

[21] Ryan J, Estefan G. Rashid A. Soil and Plant Analysis Laboratory Manual. 2nd Ed. International Center for Agriculture in Dry Areas (ICARDA): Syria; 2001.

[22] Chapman H.D, Pratt PF. Phosphorus. In: Methods of Analysis for Soils, Plants and Waters. Division of Agricultural Science, University of California, Berkeley; 1961, p. 160-170.

[23] Steel RGD, Torrie JH, Dickey DA. Principles and procedures of statistics a biometrical approach. 3rd Ed. WCB/McGraw-Hill, Boston, Mass, USA; 1997.

[24] Ali L, Ali M, Mohyuddin Q. Effect of foliar application of zinc and boron on seed cotton yield and economics in cotton-wheat cropping pattern. J Agric Res 20011; 49(2):173-180.

[25] Dordas C. Foliar boron application affects lint and seed cotton yield and improves seed quality of cotton grown on calcareous soils. Nutri Cycl Agroecosys 2006; 76:19-28.

[26] Abid M, Ahmed N, Ali A, Chaudhry MA, Hussain J. Influence of soil-applied boron on yield, fiber quality and leaf boron contents of cotton (*Gossypium hirsutum* L.). J Agric Social Sci 2007; 3:7–10.

[27] Ahmad S, Akhtar LH, Ahmad S, Iqbal H, Nasim M. Cotton (*Gossypium hirsutum* L.) varieties responded differently to foliar applied boron in terms of quality and yield. Soil Environ 2009;28:88-92.

[28] Singh K, Rathore P, Gumber RK. Effects of foliar application of nutrients on growth and yield of Bt cotton (*Gossypium hirsutum* L.). Bangl J Bot 2015; 44:9-14.

[29] Girgis EA. Effect of foliar spraying with Zinc, Iron, Manganese and their combinations on growth and yield of cotton variety Giza 70. J Agric Res Tanta Univ 1992; 18:614-624.

[30] Wahdan A, Gamalat, Ghourab MHH, Wassel OM. Physiological effect of potassium fertilizer and some micronutrients on productivity and chemical composition of Egyptian cotton (Giza 76). Menofia J Agric Res 1994; 19:1651-1663.

[31] Abd El-Shafy NA. Egyptian cotton varieties response to foliar nutrition with microelements. J Agric Sci Mansoura Univ 1998; 23:5275-5285.

[32] Gobi R, Vaiyapuri V. Effect of sulphur and micronutrients (zinc and boron) on growth, yield attributes and quality of cotton. Int J Curr Res 2012; 4:357-359.

[33] Yaseen M, Wazir A, Shahbaz M. Role of foliar feeding of micronutrients in yield maximization of cotton in Punjab. Turk J Agric 2013; 37:420-426.

[34] Bohnsac CW, Albert LS. Early effects of boron deficiency on indoleacetic acid oxidase levels of squash root tips. Plant Physiol 1977; 59:1047–1050.

[35] Kausar MA, Ali S, Iqbal MM. Zinc nutrition of three rice varieties in alkaline soils. Pak J Soil Sci 2001; 20:9-14.

[36] Stewart JMD. Integrated events in the flower and fruit. In: Mauney JR, Stewart JMD. editors. Cotton physiology. Cotton Foundation Reference Book Series No. 1, Memphis, TN: National Cotton Council of America; 1986, p. 261–297.

[37] Khan MU, Qasim M, Khan I. Effect of zinc fertilizer on rice grown in different soils of Dera Ismail Khan. Sarhad J Agric 2007; 23:1033-1040.

[38] Rio TM. 2015. http://www.riotintominerals.com/advanced_search.asp?q=boron&gobutton=Go#results as accessed on 8 August 2015.

[39] Wójcik P, Wojcik M, Klamkowski K. Response of apple trees to boron fertilization under conditions of low spoil boron availability. Sci Hortic 2008; 116:58–64.

[40] Westmark PR, Gardiner SJ Smith BD. Selective monosaccharide transport through lipid bilayers using boronic acid carriers. J Am Chem Soc 1996; 118:11093–11100.

[41] Prasad MNV. Plants that accumulate and/or exclude toxic trace elements play an important role in phytoremediation. In: Prasad MNV, Sajwan KS, Naidu R, editors. Trace elements in the environment biogeochemistry, biotechnology and bioremediation. Taylor and Francis, Boca Raton, FL; 2006.

[42] Aref F. The effect of zinc and boron interaction on residual available phosphorus and zinc in the soil after corn harvest. Soil Environ 2007; 26:157-163

[43] Siddiqui MH, Oad FC, Abbasi MK, Gandahi AW. Zinc and boron fertility to optimize physiological parameters nutrient uptake and seed yield of sunflower. Sarhad J Agric 2009; 25:53-57.

[44] Neena K, Chatterjee C. Influence of variable zinc on yield oil content and physiology of sunflower. Comm Soil Sci Plant Anal 2001; 32:3023-3030.

[45] Marschner H. Mineral nutrition of higher plants. 2nd Ed. Academic Press, London; 1997.

[46] Robertson GA, Loughman BC. Modification of phosphate transport in *Vicia faba* by boron deficiency growth regulators and metabolic inhibitors. In: Zimmermann U, Dainty I, editors. Membrane transport in plants. Springer, Berlin, Heidelberg, New York; 1974, p. 444-449.

[47] Parr AJ, Loughman BC. Boron and membrane functions in plants. In: Robb DA, Pierpoint WS, editors. Metals and micronutrients uptake and utilization by plants. Acad. Press, London; 1983, p. 87-107.

[48] Pooniyaa V, Shivaya YS, Ranab A, Nainb L, Prasannab R. Enhancing soil nutrient dynamics and productivity of Basmati rice through residue incorporation and zinc fertilization. Eur J Agron 2012; 41:28– 37.

[49] Pollard AS, Parr AJ, Loughman BC. Boron in relation to membrane function in higher plants. J Exp Bot 1977; 28:831-841.

[50] Goldbach HE. Influence of boron nutrition on net uptake and efflux of 32P and 14C-Glucose in *Helianthus annuus* roots and cell cultures of *Daucus carotat*. Plant Physiol 1985; 118:431-438.

[51] Langowski L, Ruzicka K, Naramoto S, Kleine-Vehn J. Friml J. Trafficking to the outer polar domain defines the root-soil interface. Curr Biol 2010; 20:904-908.