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Potassium and Boron Fertilization Approaches to Increase Yield and Nutritional Attributes in Maize Crop

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Abstract: Potassium (K) and boron (B) are two important plant nutrients, which have ability to influence their bioavailability in soil-plant ecosystem. They may cause deficiency or may increase availability of each other. To identify their interaction, a field experiment was designed to identify interactive behaviour influencing their bioavailability, growth, yield and nutritional attributes of maize crop, using K (0, 100, 125 and 150 kg ha^{-1}) and B (0, 8 and 16 kg ha^{-1}). As compared to the control, the growth, yield and nutritional attributes were increased by combined fertilization of K and B than their sole application. Grain yield was increased to 65% with combined fertilization of K and B @125 and 16 kg ha^{-1}, respectively, with reference to control. Concentrations of K in leaf and grains were increased 253% and 322% with combined fertilization (150 Kg ha^{-1} of K and 8 Kg ha^{-1} of B). Fertilization of K and B also increased B concentration in leaf and grains by 179% (150 Kg ha^{-1} of K and 16 Kg ha^{-1} of B) and 370% (125 Kg ha^{-1} of K and 16 Kg ha^{-1} of B). From the experiment, it was concluded that K and B are one of the essential nutrients for maize to complete its life cycle and also to increase yield parameters of maize crop. Application of 125 Kg ha^{-1} of K and 8 Kg ha^{-1} of B is suitable and economical for maize crop to increase crop productivity.

Key words: Economical fertilization, Maize productivity, Potassium boron interaction, Yield enhancement.

INTRODUCTION

Maize (*Zea Mays* L.) crop has been classified as the 3rd most important cereal crop, following wheat and rice. World population is growing fastly leading to an increased sufficient food requirements (Aslam *et al*., 2015), and the expected maize need will increase by 45% till 2020 (James, 2003). The production of maize in Pakistan was 5,271 thousand tonnes in year 2015-16 and 6,130 thousand tonnes in 2016-17, showing an increase of 3.8% (Economic Survey of Pakistan, 2016-17). It is advised as a sufficient source of carbohydrates to the livestock production and human food; similarly, it acts significantly important in textile industry as well as in pharmaceutical industry (Law-Ogbomo, 2009). The importance of maize has been increased several folds in recent years after the discovery of its use in bio-fuel production (Księżak *et al*., 2012).

Potassium (K) is substantially an important nutrient for plant growth, and has the capability to maximize plant growth and it influences soil-plant interactions as well (Xie *et al*., 2011). As, for acting as an essential nutrient for crop production and its development; it acts as a co-factor for more than 40 enzymes that are involved in metabolic pathways directly (Clarkson and Hanson, 1980; Marschner, 2011). Its application effects on turgor potential, opening and closing of stomata, relative water contents, photosynthetic rate, leaf water potential, grain weight, transpiration rate, grain yield, biological yield of crops and disturbed consumption mechanism of fixed C (Mengel and Kirkby, 2001; Aslam *et al*., 2014).

Boron (B) also has an important role during the growth and development of a crop (Brown *et al*., 2002). Its deficiency is wide spread in agriculture ecosystem and estimated around 50% cereal crops, cultivated on B deficient soils that generate negative impacts on grain production as well as the nutritional quality of the concerned crop (Cakmak, 2002).

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Deficiency of B is widely distributed than any other micronutrient, affecting reproduction and lowering the yield of crops (Shukla *et al*., 2015; Chatterjee *et al*., 2014). It is thought to be the part of plant cell wall, acting as structural component for its stability and integrity (Bassil *et al*., 2004). The presence of di-ester bond makes B suitable to participate in cross linkage of many other molecules (Chormova *et al*., 2014; Brown *et al*., 2002). It contributes in metabolic activities of nucleic acid, proteins, indole acetic acid, carbohydrates and phenol metabolism (Goldbach *et al*., 2001).

In soil environment, nutrients interact with each other, thereby improving their availability or may reduce it, depending upon the kind of interaction that may be synergistic or antagonistic (Imran *et al*., 2016). The use of integrated nutrient management technique by supplying balance fertilization has been observed a major technique to save the soil fertility and also to obtain maximum crop production with good quality grains as well as enhances water use efficiency (Fan *et al*., 2005).

The need of research arises because of less research for interaction of K and B and lack of knowledge regarding their role in increased production. The aim of current experiment was the identification of interaction between both the nutrients and their role in increasing the productivity of maize crop. It could also help to find some of the correlation between K and B.

MATERIALS AND METHODS

Soil conditions: During current study, the field experiment was conducted at Research Field of Faculty of Agricultural Sciences and Technology (FAS&T), Bahauddin Zakariya University, Multan. To determine the physico-chemical properties, soil samples were taken randomly at 0-30 cm depth from the experimental area. These samples were air-dried to minimize the moisture contents, sieved by using 2-mm sieve. A composite mixture was prepared by thoroughly mixing. A true representative soil sample was taken from mixed soil and used for determination of physio-chemical properties of soil used for experiment with the help of standard laboratory methods (Table 1). From the analysis of these samples, it was concluded that soils are slightly alkaline and calcareous with low availability of B (0.09 ppm) (Rahman *et al*., 1999) and medium availability of K exchangeable K (107 ppm) (Chung *et al*., 2002).

Table 1: Physico-chemical properties of collected soil samples.

Name	Value	Status	Method
Texture		Loam	USDA classification
ECe (dS/m)	0.71	Slightly saline	Electric conductivity of saturated soil paste extract
pHs	8.4	Medium alkaline	pH of saturated soil paste
$CaCO_3$ (%)	0.61	Calcareous	Acid dissolution (Allison and Moodie, 1965)
Organic matter (%)	0.49	Very low	Walkley-Black method (Jackson, 1962)
Nitrogen (%)	0.031	Very low	Kjeldahl's apparatus (Jackson, 1962)
Available P (mg/kg)	9.27	Low	NaHCO3 method (Olsen and Sommers, 1982)
Exchangeable K (mg/kg)	107	Medium	Richards, 1954
Boron (mg/kg)	0.09	Low	HCl extraction (Ponnamperuma *et al*., 1981)

Growth conditions: A variety of maize hybrid (cv. Monsanto DK-6142) was grown for the experiment in the growing season of year 2016. The treatments were applied in 3 replicates in a plot (3m × 5m) size and were arranged, using randomized complete block design (RCBD). The seeds were sown by maintaining a standard distance from plant-to-plant (22.5 cm) and row to row (75 cm). Doses of K, used in this experiment, were 0, 100, 125 and 150 Kg ha^{-1} and the B was 0, 8 and 16 Kg ha^{-1}. Potassium and B were fertilized as potassium sulphate (K_2SO_4) and boric acid (H_3BO_3) as a source of fertilizers. Requirement of nitrogen (N) and phosphorus (P) was fulfilled with application of recommended doses of N (250 Kg ha^{-1}) and P (150 Kg ha^{-1}), using urea and diammonium phosphate (DAP) as sources. All the quantity of recommended P was fertilized at sowing time, while, N fertilization was done in three splits.

Plant analysis: At the time of physiological maturity (105 days after sowing), the crop was harvested. The physiological and chemical parameters were calculated with the use of standard methods from plant samples. Richards' method was used for K determination from plant samples, (Richards, 1954). Aliquot from digested sample (10 ml) was taken in volumetric flask and 10 ml of lithium chloride was added. The readings of K for standard and unknown solution were recorded. Determination of B in plant tissues was carried out, using the method of Chapman and Parker (1961). Dry ashing was done and plant sample aliquot (1 ml) was taken in polypropylene tube. Azomethine-H and buffer solution was added in the mixture and was allowed to stay for 30 minutes. Absorbance curves for the standard and plant samples were recorded, using spectrophotometer, at 420 nm and final readings with calibration curves were calculated.

Statistical analysis: For statistical analysis, two factorial randomized complete block design (RCBD) was used for the formation of analysis of variance (ANOVA). The treatments were analysed on the basis of least significance difference (LSD) with $p \leq 0.05$ (Steel *et al*., 1997). Statistix 9® for Windows was used for calculations (Analytical Software, Tallahassee, USA). The relationships between different variables were evaluated, using Pearson correlation.

RESULTS AND DISCUSSION

Growth parameters: A significant ($p \leq 0.05$) influence on plan height was observed by combine fertilization of K and B (Table 2). Plant height was ranging from 134.33–175 cm, in all treatments. Maximum plant height was 175 cm (150 Kg K ha^{-1} and 16 Kg B ha^{-1}), followed by 173.67 cm (150 Kg K ha^{-1} and 8 Kg B ha^{-1}), 170 cm (125 Kg K ha^{-1} and 8 Kg B ha^{-1}), 169 cm (125 Kg K ha^{-1} and 16 Kg B ha^{-1}) and 161 cm (100 Kg K ha^{-1} and 8 Kg B ha^{-1}).

Fertilization of K and B showed significant ($p \leq 0.05$) role for cob length (Table 2). Cob length varied between 17.6 to 20.1 cm. Interactive application of K and B produced maximum cob length by 14.3% (150 Kg ha^{-1} of K and 16 Kg ha^{-1} of B), followed by 13.6% (125 Kg K ha^{-1} and 8 Kg B ha^{-1}), 12.8% (125 Kg ha^{-1} of K and 16 Kg ha^{-1} of B), 12.5% (150 Kg ha^{-1} of K and 8 Kg ha^{-1} of B) and 12.1% (100 Kg ha^{-1} of K and 8 Kg ha^{-1} of B) as compared to the control.

Table 2: Growth and yield attributes of maize.

Treatments		Plant height (cm)	Cob length	Number of grains per cob	1000-grain weight (g)	Straw yield (t ha^{-1})
Interaction (Potassium × Boron)						
	K_0	134.33 e	17.60 c	265.81 d	228.33 h	10.17 i
	K_{100}	153.33 de	17.66 bc	323.96 c	240.67 g	10.29 h
B_0	K_{125}	154.00 de	17.66 c	330.19 bc	247.67 f	11.55 g
	K_{150}	156.00 d	18.20 bc	344.73 ab	252.00 e	13.20 b
	K_0	151.33 de	18.20 b	319.81 c	256.67 d	11.95 f
B_8	K_{100}	162.00 c	19.73 a	346.80 ab	262.67 c	12.96 c
	K_{125}	170.00 b	20.00 a	357.19 a	265.67 bc	14.81 a
	K_{150}	173.67 ab	19.80 a	361.34 a	269.00 a	14.85 a
	K_0	149.67 e	18.80 b	319.81 c	267.33 ab	12.25 e
B_{16}	K_{100}	161.00 c	18.80 a	350.96 a	267.67 ab	12.68 d
	K_{125}	169.00 b	19.86 a	350.96 a	266.33 ab	14.85 a
	K_{150}	175.00 a	20.13 a	353.03 a	257.33 d	14.86 a

Yield parameters: The influence of combined K and B fertilization on number of grains per cob was found significant ($p \leq 0.05$) in all treatments (Table 2). Number of grains per cob ranged from 265.81 to 361.34 in all treatments. The maximum amount obtained was 361.34, where K and B were 150 Kg ha^{-1} and 8 Kg ha^{-1} followed by 357.19 (125 Kg ha^{-1} of K and 8 Kg ha^{-1} of B), 353.03 (150 Kg ha^{-1} of K and 16 Kg ha^{-1} of B) and 350.96 (100 Kg ha^{-1} of K and 16 Kg ha^{-1} of B; 125 Kg ha^{-1} of K and 16 Kg ha^{-1} of B).

Fertilization with K and B also showed significant ($p \leq 0.05$) behaviour with 1000-grain weight (Table 2). It ranged from 228.33g–269g in all treatments. Maximum 1000-g weight was 269g (150 Kg ha^{-1} of K and 8 Kg ha^{-1} of B) that was followed by 267.67g (100 Kg ha^{-1} of K and 16 Kg ha^{-1} of B), 267.33g (16 Kg ha^{-1} of B), 266.33g (125 Kg ha^{-1} of K and 16 Kg ha^{-1} of B) and 265.67g (125 Kg ha^{-1} of K and 8 Kg ha^{-1} of B).

A significant ($p \leq 0.05$) influence was observed on straw yield with fertilization of K and B (Table 2). Straw yield ranged from 10.17 t ha^{-1} to 14.86 t ha^{-1} in all treatments. Fertilization of K and B produced maximum amount of straw yield at 14.86 t ha^{-1}, when K was 150 Kg ha^{-1} and B was 16 Kg ha^{-1}). This was followed by 14.85 t ha^{-1} (125 Kg ha^{-1} of K and 16 Kg ha^{-1} of B; 150 Kg ha^{-1} of K and 8 Kg ha^{-1} of B), 14.81 t ha^{-1} (125 Kg ha^{-1} of K and 8 Kg ha^{-1} of B) and 13.20 t ha^{-1} (150 Kg ha^{-1} of K).

It was observed that fertilization of K and B affected grain yield significantly ($p \leq 0.05$, Fig. 1). Grain yield ranged from 4.14 t ha^{-1} to 6.82 t ha^{-1} in all treatments. Fertilization of K and B increased grain yield by 64.7% (150 Kg ha^{-1} of K and 16 Kg ha^{-1} of B; 125 Kg ha^{-1} of K and 16 Kg ha^{-1} of B), 64.4% (125 Kg ha^{-1} of K and 8 Kg ha^{-1} of B), 63.2% (150 Kg ha^{-1} of K and 8 Kg ha^{-1} of B), and 42.9% (100 Kg ha^{-1} of K and 8 Kg ha^{-1} of B), as compared to the control.

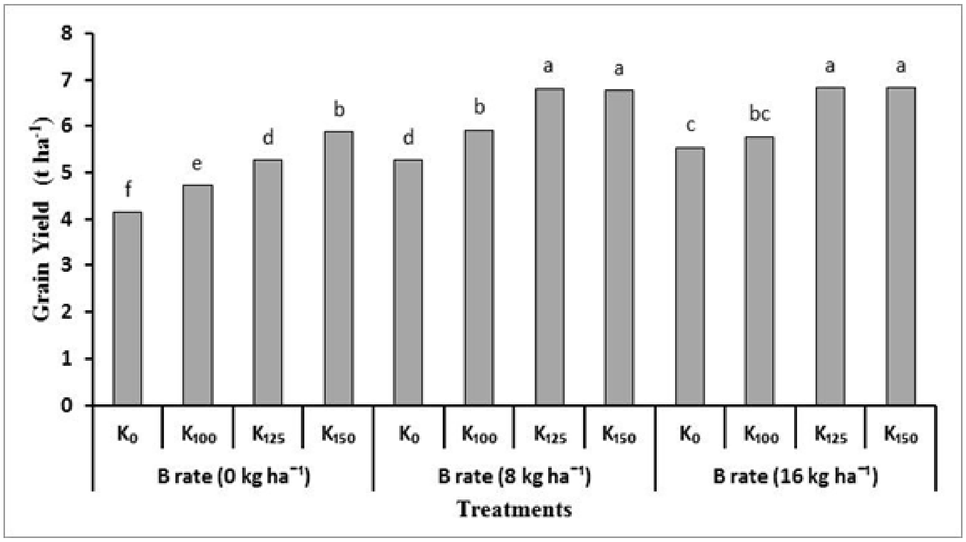

Fig. 1: Grain yield (t ha^{-1}) of maize supplied with different rates of B (0, 8 and16 kg ha^{-1}) and K (0, 100, 125 and 150 kg ha^{-1}). Different letters indicate significant differences by LSD at 5%.

Nutritional parameters: Fertilization of K and B produced significant ($p \leq 0.05$) effects on nutritional parameters of crop (Figs. 2-3). It was observed that leaf K concentration increased up to 252.5% (150 Kg ha^{-1} of K and 8 Kg ha^{-1} of B) that was followed by 247.5% (150 Kg ha^{-1} of K and 16 Kg ha^{-1} of B), 243.7% (125 Kg ha^{-1} of K and 16 Kg ha^{-1} of B), 242.5% (125 Kg ha^{-1} of K and 8 Kg ha^{-1} of B) and 233.7% (100 Kg ha^{-1} of K and 16 Kg ha^{-1} of B), as compared to control.

Grain K concentration also increased up to 326% (150 Kg ha^{-1} of K) that was followed by 321.7% (150 Kg ha^{-1} of K and 8 Kg ha^{-1} of B; 150 Kg ha^{-1} of K and 16 Kg ha^{-1} of B), 308.6% (125 Kg ha^{-1} of K), 300% (125 Kg ha^{-1} of K and 8 Kg ha^{-1} of B) and 295.6% (125 Kg ha^{-1} of K and 16 Kg ha^{-1} of B), as compared to control (Fig. 2).

Fertilization of K and B also improved B leaf and B concentration efficiently ($p \leq 0.05$) (Fig. 3). Leaf B concentration was founded high up to 179.4% (150 Kg ha^{-1} of K and 16 Kg ha^{-1} of B). This was followed by 149.8% (125 Kg ha^{-1} of K and 16 Kg ha^{-1} of B), 133.1% (100 Kg ha^{-1} of K and 16 Kg ha^{-1} of B), 123.2% (150 Kg ha^{-1} of K and 8 Kg ha^{-1} of B) and 118.7% (125 Kg ha^{-1} of K and 8 Kg ha^{-1} of B), as compared to that with no application of K and B was done.

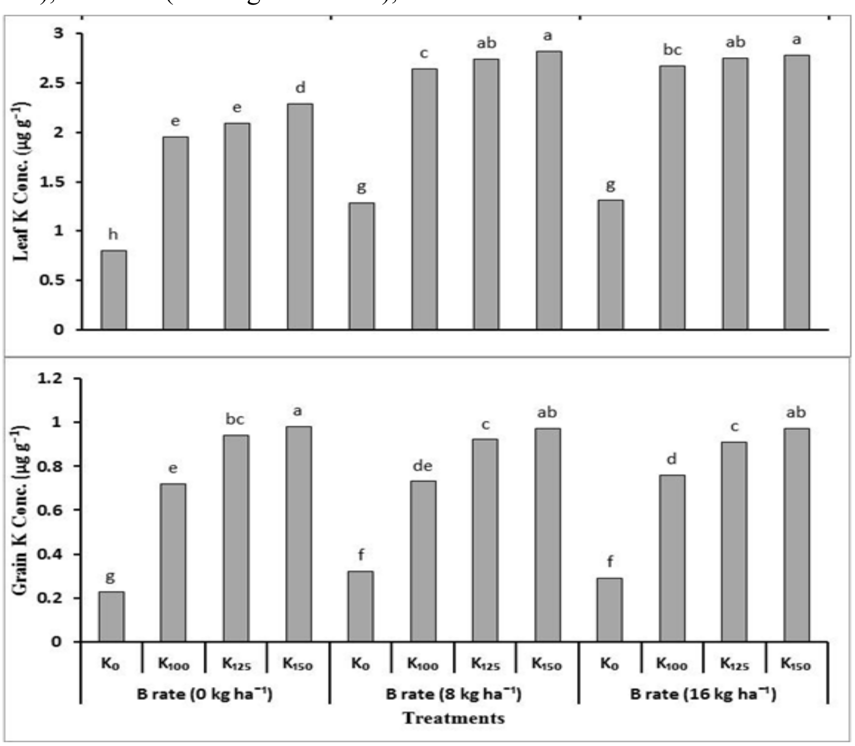

Fig. 2: Concentration of potassium in leaves and grains of maize supplied with different rates of B (0, 8 and 16 kg ha^{-1}) and K (0, 100, 125 and 150 kg ha^{-1}). Different letters indicate significant differences by LSD at 5%.

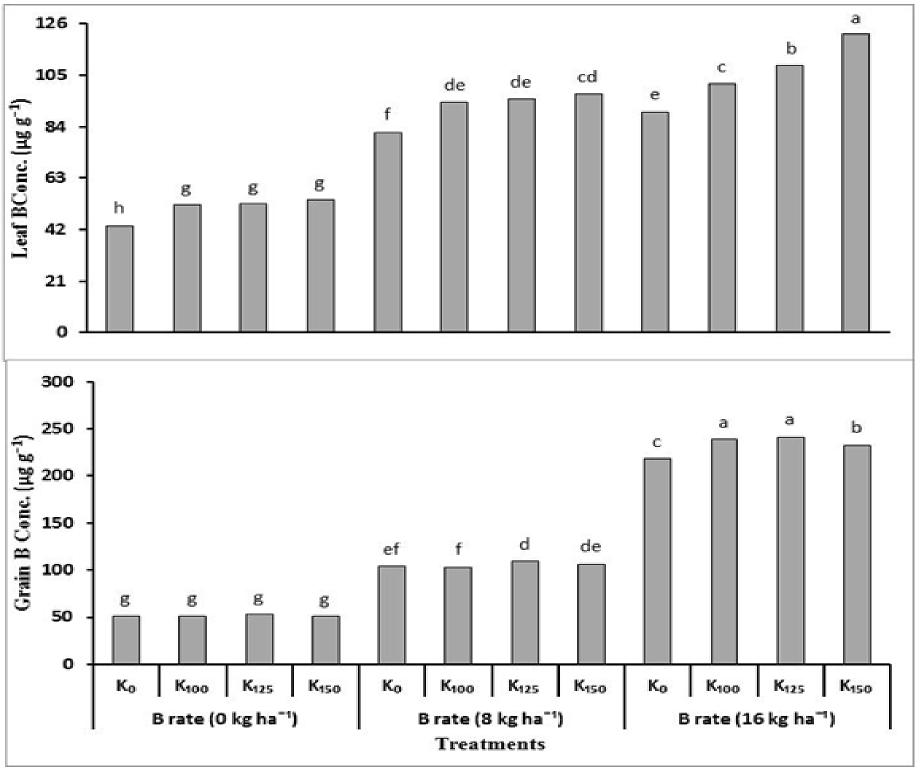

Fig. 3: Concentration of boron in leaves and grains of maize supplied with different rates of B (0, 8 and16 kg ha^{-1}) and K (0, 100, 125 and 150 kg ha^{-1}). Different letters indicate significant differences by LSD at 5%.

Grain B concentration was also increased 369.9% (125 Kg ha^{-1} of K and 16 Kg ha^{-1} of B) along with 365.1% (100 Kg ha^{-1} of K and 16 Kg ha^{-1} of B), 353.4% (150 Kg ha^{-1} of K and 16 Kg ha^{-1} of B), 324.4% (16 Kg ha^{-1} of B) and 112.7% (125 Kg ha^{-1} of K and 8 Kg ha^{-1} of B) as compared to controlled.

Fertilization of K and B was helpful for improved yield attributes and growth parameters of maize crop (Table 2, Figs. 1-3). From this study, it was concluded that the use of K and B improved growth attributes that were effective for improvement of grain yield (Table 2). It was observed that the application of 10 mmol/L of potassium sulphate resulted in improved vegetative growth along with root growth (Tzortzakis, 2010). The maximum amount of shoot length was measured when nutrient solution contained 10 mM of K, that is because K helped to improve growth factors (Egilla *et al*., 2001). Boron as essential nutrient was identified in 20th century but at the moment, it is widely accepted as a major nutrient for all plants to complete their metabolic activities (Blevins and Lukaszewski, 1998). From various studies, it has been observed that B is involved in several processes including cell structure and its functioning, maintenance of membranes and promoting metabolic activities (Brown *et al*., 2002). It was observed that the plant height improved with the application of B, that indicated B role in elongation of cells and to increase cell division process (Mouhtaridou *et al*., 2004) and also improved meristematic growth of plants up to certain level (Khan *et al.,* 2006). Boron was involved in cross linkage on pectin compounds during formation of cell wall structure (O'Neill *et al*., 2004). Deficiency of micronutrients, especially B, is widespread in global world (Alloway, 2008). Its deficiency leads to unfavourable conditions for growth and development of plants, in agricultural ecosystem, low availability of B tends to inhibit plant growth, tissues growth besides affecting reproductive system (Brown *et al*., 2002). Similarly, deficiency of B caused retardation of apical growth/extension of plant, induced cracks in stem and petioles, led to necrosis of apical buds and shedding of fruits in fruit trees (Goldbach, 1997; Silva *et al*., 2008).

In the current study, it was also observed that the application of K and B enhanced grain yield along with early uniform crop stand and vital seedling growth impact (Table 2; Fig. 1). It has been observed that the application of K and B has significantly translocated the assimilated sunlight from vegetative parts to crop to the productive parts (Reddy *et al*., 2003). This could be the cause of higher production due to increased translocation of nutrients that might be the reason for enhancement in leaf K concentration, grain K concentration, leaf B concentration and grain B concentration (McVicar *et al*., 2012; Reddy *et al*., 2003). Ahmad *et al*., 2015 reported that maximum 1000 grain weight was taken when K was applied. These results were according to the findings of Hussain *et al*. (2002) and Stanford (1973) who proposed that biological yield will be maximum with fertilization of essential nutrient with adequate water supply. Studies have shown that an increased amount of K increased root and shoot dry matter of maize crop at the rate of application 8 Mmv (Celik *et al*., 2010). Similar results for maximum fresh root and shoot weight were obtained when K was applied at the rate of 150 ppm under a pot experiment (Wakeel *et al*., 2002). It was concluded that maximum amount of shoot dry weight was obtained due to fast availability of K under stress conditions that increase productivity (Nawaz *et al*., 2006). Application of K in farming system increased the yield of maize grains by 9.9-14.9%, as compared to those where no K was applied (Niu *et al*., 2011). Similarly, it was observed that K fertilization increased maize grain yield up to 46% in a 19-year experiment (He *et al*., 2012). In zero tillage system application of K increased grains yield by 11.5% and, mulch tillage system, it was increased till 8.6% in Canada (Vyn *et al*., 2002).

Nutritional values of grains were improved with the application of K and B fertilizers (Barker and Pilbeam, 2015). Positive impact on photosynthesis, activation of many enzymes and transportation of assimilated compounds towards the stem was at peak, when K application was done besides improving the plant physiology (Malvi, 2011). Simlarly, water use efficiency, growth, cell division, quick transfer of proteins and carbohydrates contents were improved significantly with K application (Marschner, 1995). It was observed that K helped in tolerance against drought conditions in maize (Waraich *et al*., 2011), because it can stimulate water uptake and osmotic adjustment by controlling turgor pressure that increased capability of tolerance (Bukhsh *et al*., 2012).

Discussing about correlation of K and B, it was observed that grain K concentration with correlation to leaf K concentration and grain B concentration with relation to leaf B concentration supported each other directly to enhance their concentration as compared to that treatment, where no application of K and B was done (Fig. 4 A-B). However, in case of grain K concentration and grain B concentration did not show any significant result in correlation (Fig. 4 C). In case of leaf K concentration and grain B concentration (Fig. 5 A), along with grain K concentration to leaf B concentration (Fig. 5B) showed very small positive correlation.

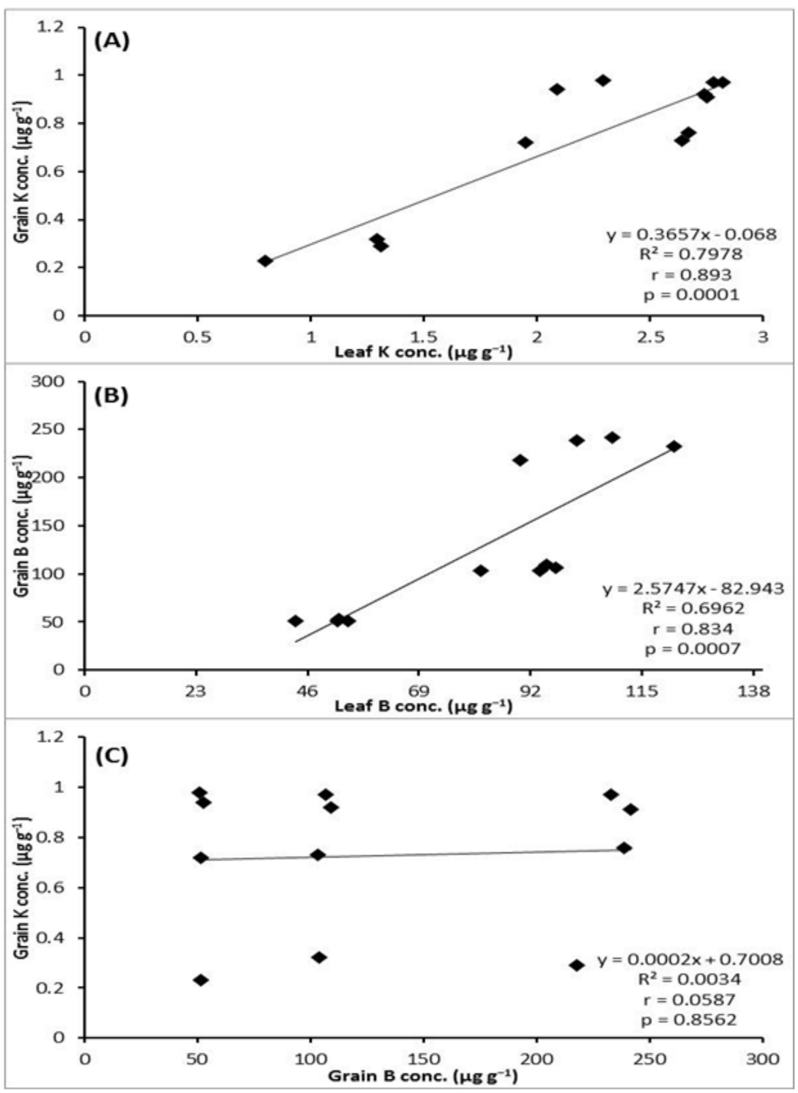

Fig. 4: Relationship (Pearson correlation coefficients, r) of A) Grain and Leaf K, B) Grain and Leaf B, and C) Grain K and B concentration in maize crop.

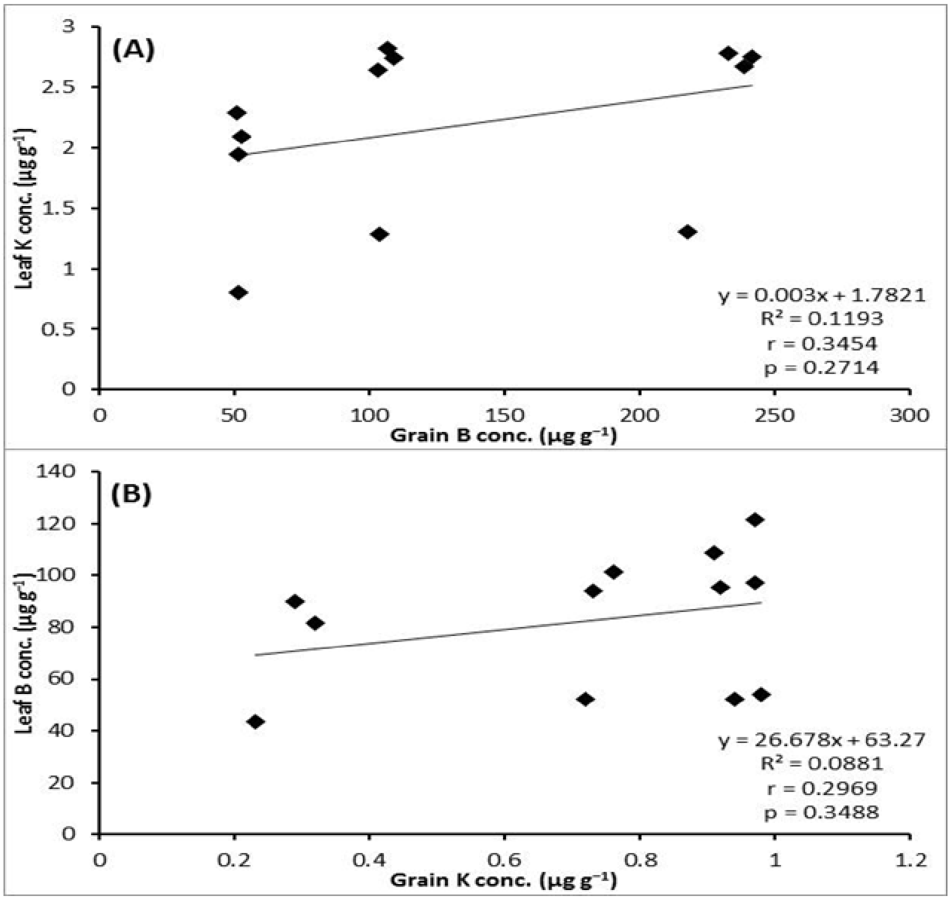

Fig. 5: Relationship (Pearson correlation coefficients, r) of A) Leaf K and Grain B and B) Leaf B and Grain K concentration in maize crop.

CONCLUSION

During current study, a positive correlation was found in a combined application of K and B, that resulted in improved growth, nutritional and yield attributes, as compared to their sole application. The concentrations of K and B were also high in leaves and grains of maize, where combined application was also followed. All the treatments showed significant increase in growth, nutritional and yield attributes with combined application of K and B than the sole or controlled application. It is recommended to increase growth, nutritional and yield parameters of maize crop by a combined application of K and B. Further, in-depth studies are required to find their correlation in soil environment and in residual fractions.

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