

The effect of boron and zinc application on concentration and uptake of nitrogen, phosphorous and potassium in corn grain

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Abstract

A farm experiment with corn grown on Zinc (Zn) and boron (B) deficient soil was conducted to study the effect of Zn and B on the concentration and total uptake of N, P and K in corn grain at Fars Province of Iran. Treatments included five levels of Zn (0, 8, 16 and 24 kg ha⁻¹ Zn added to the soil and Zn foliar spray with a 0.5 percent concentration) and four levels of B (0, 3 and 6 kg ha⁻¹ B added to the soil and B foliar spray with a 0.3 percent concentration) in a completely randomized block design. The results of this study showed that the application of B at low Zn levels had no significant effect on the NPK concentrations in the grain, but at high Zn levels, increased NPK concentrations in the grain. Therefore, a high Zn content in the soil helped increasing the N, P and K concentrations and P uptake in the grain by B application; that is, at high Zn levels, there was a synergism between B, N, P and K.

Keywords: Nutrition, Macronutrients, NPK, boron, zinc, corn plant

Introduction

Zinc is involved in a large number of enzymes as a cofactor. For example, it is involved in activation of different enzymes such as dihydrogenase, aldolase, isomerase, transphosphorase and DNA polymerase (Marschner, 1995). Zinc deficiency is a very important nutrient problem in the world's soils. Total Zn concentration is sufficient in many agricultural areas, but available Zn concentration is deficient because of different soil and climatic conditions. Soil pH, lime content, organic matter amount, clay type and amount and the amount of applied phosphorus fertilizer affect the available Zn concentration in soil (Adiloglu & Adiloglu, 2006). Zinc deficiency rate was determined as a 30 % in the world (Sillanpaa, 1982). In spite of the fact that the total amount of Zn in the soil is relatively high, but a small fraction of it is available to the plant. Numerous factors affect Zn availability, including the soil calcium carbonate content, which reduces the Zn availability in the soil (Dutta *et al.*, 1989; Mandal *et al.*, 1992). The interaction among nutrient elements is very important for plant nutrition. Boron x Zn interaction among these interactions has been crucial in the Zn deficient soils, in recent years (Alkan *et al.*, 1998). Among the micronutrients, Zn deficiency is perhaps most extensive in the world. Zinc deficiency is most common in low- and high pH soils, low- and high organic matter, sandy, sodic, calcareous soils and waterlogged without ventilation (Takkar & Walker, 1993). Corn is among the plants most sensitive to Zn deficiency (Aref, 2010a). Boron plays a very important role in vital functions of the plant, including meristem tissue cell division, petal and leaf bud formation, vascular tissue repair, sugar and hydrocarbon metabolism and their transfer, RNA and indoleacetic acid metabolism, membrane stability, cytokinin production and transfer, pollen budding and seed formation (Shelp, 1993; Marschner, 1995). Boron and Zn deficiency upset the order of grains on the corns and make them deformed so that some parts of the corn ear are free from grains (Marschner, 1995). Boron deficiency is common in sandy

and highly calcareous rich soils since there is an interaction between the Ca ion and the available B and high Ca levels at high pH reduces B uptake (Marschner, 1995).

A negative Zn-B interaction has been seen in the plant (Harsharn *et al.*, 1998). Mozafar (1987), by studying the effects of 12 nutrients on the corn graining, observed that concentrations of Zn, B, Cu, Mn, Ca, Mn, K, P, N and Na in corn ear and concentrations of elements Zn, B, Fe, Cu, Mn, Mo, Ca and P in the unripe corn ear stem were similar and no significant difference was seen between them.

Considering numerous cases of corn use in human, animal and poultry nutrition and extraction of about 500 different products, from it, we see that the grain being rich in nutrients, including P and K plays an important role in human nutrition. The grain being rich in such elements is also an evidence for improve of the harvest, qualitatively and quantitatively. Therefore, by studying Zn and B interaction in the grain, we can find its indirect effects that arte improvement of the harvest, qualitatively and quantitatively, while enriching the grain as well. Also, it has been shown that if we use grains rich in these elements as seeds, we can improve the harvest, qualitatively and quantitatively.

Materials and methods

A field experiment was conducted at the farm of Aref, in Abadeh Tashk, Fars province of Iran, on the corn (*Zea mays* L.), cultivar "Single Cross 401" during 2009 cropping season. The site is located 200 km northeast of Shiraz, at latitude 29° 43' 44" N and longitude 53° 52' 07" E and 1580 m altitude. Before implementing the project sampling from the soil (0-30 cm depths) was made in order to select a zone in which the available amount of Zn and B was low (less than 1 mg kg⁻¹ extracted by methods of DTPA and hot water, respectively). This soil had a loam texture, pH of 8.2, 0.59% organic matter, 229 mg kg⁻¹ available K, 12.1 mg kg⁻¹ available P, DTPA extractable Fe, Mn, Zn and Cu concentration were 1.65, 8.14, 0.32

and 0.62 mg kg⁻¹ and available B with hot water extractable was 0.78 mg kg⁻¹.

This experiment included 20 treatments and 3 replications in the form of completely randomized block design and factorial that combinations of five levels of Zn (0, 8, 16 and 24 kg ha⁻¹ Zn added to the soil, and Zn foliar spray with a 0.5 percent concentration) and four levels of B (0, 3, and 6 kg ha⁻¹ B added to the soil, and B foliar spray with a 0.3 percent concentration). Nitrogen, P and K used at 180, 70 and 75 kg ha⁻¹ according to the recommendation, from sources of urea (with 46% N), triple super phosphate (with 46% P₂O₅) and potassium sulfate (with 50% K₂O), respectively, were added to all treatments. Half of the urea was used when planting and the remainder two times: At vegetative growth and when the corn ears were formed. Potassium and P used before planting. Zinc and B, from zinc sulfate and boric acid sources, respectively, were used by two methods, adding to the soil and spraying. Addition to the soil was made at the time of plantation and the sprayings were made at 0.5% Zn sulfate and 0.3% boric acid two times: one at vegetative growth stage and the other after corn ears formation. The Zn and B were both applied to the leaves with uniform coverage at a volume solution of 2500 L ha⁻¹ using a knapsack sprayer. Each experimental plot was 8 m length and 3 m width, had 5 beds and 4 rows, equally spaced, and seeds 20 cm apart on the rows. At the end of the growth stage the grain yield and NPK concentrations in the leaf were measured.

Analysis of the grain and the soil was carried out using common lab procedures (Soil and Plant Analysis Council, 2004). Soil particle size distribution was determined by the hydrometer method (Gee & Bauder, 1986), organic matter (OM) content by the Walkley - Black method and pH was determined at a 1:2.5 soil/water ratio. Soil available K was determined by 1 M NH₄OAc extraction and K assessment in the extract by flame photometer (Thomas, 1982). Soil available P was measured by Olsen method. Available Fe, Zn, Mn and Cu in the soil were first extracted by DTPA and then were read by atomic absorption. The soil available B was extracted by hot water and then was measured by spectrophotometer by curcumin method, considering the intensity of the color produced. Total elements in grain were analyzed after digestion of dry and milled plant material with HCl. Total N was measured by micro-Kjeldahl method, P by spectrophotometer, K by flame photometer.

Statistical analysis of data was made using SAS software with Duncan test and regression equations via the SPSS program.

Table 1. The result of soil analysis

Soil properties	Values
Depth of soil(cm)	0 -30
Soil texture	Loam
pH	8.2
EC (ds m ⁻¹)	2.41
Organic matter(%)	0.59
Nutrients (mg kg ⁻¹)	
P	12.1
K	229
Fe	1.65
Mn	8.14
Zn	0.32
Cu	0.62
B	0.78

Results and discussion

The results of soil analysis before plantation are presented in Table 1. The soil available K was high but P content in the soil was lower than the critical level suggested in scientific sources (Rashid *et al.*, 1994; Karimian & Yasrebi, 1995). Karimian and Ghanbari (1990) have reported the critical P level by the Olsen method in calcareous soils as 18 mg kg⁻¹.

The soil Mn content was high but the soil Zn, B, Cu and Fe contents in the soil were lower than the critical level. Sims and Johnson (1991) have reported the critical levels of Fe, Zn, Mn and Cu by the DTPA extraction method and B by the hot water in the soil method to be 2.5-5, 0.2-2, 1-5, 0.1-

2.5 and 0.1-2 mg kg⁻¹, respectively.

Table 2. The effect of Zn and B on the N concentration (%) by the grain*

B levels (kg ha ⁻¹)	Zn levels (kg ha ⁻¹)					Mean of B levels
	0	8	16	24	Foliar Spray	
0	1.62 bcd	1.6 bcd	1.69 bcd	1.5 d	1.75 abcd	1.63 a
3	1.76 abcd	1.63 bcd	1.65 bcd	1.8 abc	1.67 bcd	1.72 a
6	1.83 ab	1.64 bcd	1.81 abc	1.69 bcd	1.71 bcd	1.74 a
Foliar Spray	1.55 cd	1.66 bcd	1.76 abcd	1.7 bcd	1.99 a	1.73 a
Mean of Zn levels	1.69 ab	1.63 b	1.73 ab	1.67 ab	1.78 a	

*The same letters are not significantly different in each row or in each column at 5% level by Duncan's test

Nitrogen concentration in the grain

The effects of Zn and B on the grain N concentration were insignificant (p < 0.05) (Table 2). The study of the effect of Zn and B interaction on the grain N concentration showed that B use only at 24 kg ha⁻¹ Zn level increased N concentration in the grain. Application of 3 kg ha⁻¹ B at 24 kg ha⁻¹ Zn increased grain N concentration from 1.5 to 1.8 percent (20% increase as compared with no B use at this Zn level) while other B levels showed no significant effect. At other Zn levels, application of B had no effect on the grain N concentration. Zinc spraying use, only at the B solution spraying level increased grain N concentration from 1.55 to 1.99 percent, showing a 28.38 percent increase as compared with the no Zn use. The lowest and the highest N concentration in the grain, 1.5 and 1.99%, were observed at using 24 kg ha⁻¹ Zn and joint use of Zn and B spraying, respectively. Except for these two treatments, other treatments showed no significant difference from the control.

Nitrogen uptake by the grain

The main effect of Zn on the N uptake by the grain (kg ha⁻¹) was significant (p < 0.05) (Table 3). The lowest mean N uptake by the grain, at 125.99 kg ha⁻¹, was seen



Table 3. The effect of Zn and B on the N uptake (kg ha^{-1}) by the grain*

B levels (kg ha^{-1})	Zn levels (kg ha^{-1})				Foliar Spray	Mean of B levels
	0	8	16	24		
0	108.83 b	138.69 ab	128.51 ab	115.65 b	153.68 ab	129.07 b
3	145.2 ab	148.07 ab	148.37 ab	165.99 a	146.28 ab	150.78 a
6	133.5 ab	142.45 ab	174.9 a	138.09 ab	153.84 ab	148.56 a
Foliar Spray	116.43 b	144.08 ab	171.9 a	174.53 a	169.38 a	155.26 a
Mean of Zn levels	125.99 b	143.32 ab	155.92 a	148.57 a	155.79 a	

*The same letters are not significantly different in each row or in each column at 5% level by Duncan's test

at no Zn level. With applying 16 and 24 kg ha^{-1} Zn, N uptake by the grain increased from 125.99 at zero Zn level to 155.92 and 148.57 kg ha^{-1} , respectively (23.76 and 17.92 percent increase, respectively), but no significant difference was seen between these two Zn levels. Zinc spraying increased grain N uptake to 155.79 kg ha^{-1} , showing a 23.65% increase relative to zero Zn level; but there was no significant difference between the Zn spraying and applying Zn to the soil in that regard. The highest N uptake by the grain, which is 155.92 kg ha^{-1} , was seen at 16 kg ha^{-1} Zn level.

The effect of applying different B levels on the N uptake by the grain was significant at 5% level. The lowest grain N uptake, 129.07 kg ha^{-1} , was seen at zero B level. Boron use at all levels (applying to the soil and spraying) increased grain N uptake relative to zero B use. The use of 3 and 6 kg ha^{-1} B increased grain N uptake from 129.07 at zero B level to 150.78 and 148.56 kg ha^{-1} , respectively (16.82 and 15.1 % increase, in that order); but there was no significant difference between these two B levels. Boron spraying, too, increased grain N uptake from 129.07 to 155.26 kg ha^{-1} , a 20% increase relative to zero B level; but no significant difference was seen between Zn spraying and its addition to the soil. The highest grain N concentration was due to B spraying.

Studying the effect of Zn and B interaction on the grain N uptake showed that B use at highest Zn level (24 kg ha^{-1} Zn), increased grain N uptake but at other Zn levels, it showed no significant effect on the N uptake. At 24 kg ha^{-1} Zn level, the use of 3 kg ha^{-1} B and B spraying significantly increased grain N uptake from 115.65 kg ha^{-1} to 165.99 and 174.53 kg ha^{-1} , respectively (43.52 and 50.91 percent increase relative to zero B use), but the use of 6 kg ha^{-1} B had no significant effect.

Zinc use at B spraying level, significantly increased grain N uptake but at other B levels, had no significant effect on the N uptake. At B spraying level, application of 16 and 24 kg ha^{-1} Zn, increased grain N uptake from 116.43 to 171.9 and 174.53 kg ha^{-1} , respectively (47.64 and 49.9 percent increase, respectively). Zinc spraying at B spraying level, too, increased grain N uptake to 169.38 kg ha^{-1} (45.48% increase) but no significant difference

was seen with the case in which Zn was directly applied to the soil.

The lowest N uptake by the grain, 108.83 kg ha^{-1} , was seen in the case where no Zn and no B was used (the control). The highest N uptake by the grain, 174.9 kg ha^{-1} , was seen when 6 kg ha^{-1} B + 16 kg ha^{-1} Zn was used, leading to 60.71% increase relative to the control.

Phosphorous concentration in the grain

The use of different Zn levels had no significant effect on the grain P content relative to no Zn level but Zn application in spray form led into a significant reduction in grain P content as compared with 8 kg ha^{-1} Zn level (Table 4). The main effect of B on the grain P content (%) was insignificant at 5% level.

In analysis of Zn and B interaction affecting the grain P content it was seen that application of 3 kg ha^{-1} B at high Zn level (24 kg ha^{-1} Zn) increased grain P content from 0.28 to 0.35 % (25% increase); but at other Zn levels, it had no significant effect on the grain P content. At B spraying level, only application of 8 kg ha^{-1} Zn increased grain P content from 0.28 to 0.35% (25% increase); but at other B levels, Zn application had no significant effect on the grain P content. Of course no treatment showed a significant difference from the control.

The increase of P concentration in the grain using B is reported by Ming *et al.* (1992) and its decrease is reported by Rengel and Graham (1995) and Aref (2010b). In this research Zn application had no effect on grain Zn content, thus by Zn application, K concentration in the grain did not change.

Table 4. The effect of Zn and B on P concentration in the grain (%)*

B levels (kg ha^{-1})	Zn levels (kg ha^{-1})				Foliar Spray	Mean of B levels
	0	8	16	24		
0	0.32 abcd	0.32 abcd	0.30 abcd	0.28 d	0.30 abcd	0.31 a
3	0.33 abcd	0.34 abcd	0.31 abcd	0.35 abcd	0.32 abcd	0.33 a
6	0.30 abcd	0.33 abcd	0.36 a	0.31 abcd	0.29 cd	0.32 a
Foliar Spray	0.28 d	0.35 ab	0.31 abcd	0.31 abcd	0.29 bcd	0.31 a
Mean of Zn levels	0.31 ab	0.34 a	0.32 ab	0.31 ab	0.30 b	

*The same letters are not significantly different in each row or in each column at 5% level by Duncan's test

Phosphorous uptake by the grain

The main effect of Zn on the P uptake by the grain (kg ha^{-1}) was significant at 1% level (Table 5). Application of Zn to the soil at all levels, caused an increase P uptake by the grain as compared with no Zn level, but Zn application in spray form had no significant effect on it at other Zn levels. The least mean P uptake by the grain, 22.98 kg ha^{-1} , was seen at no Zn level. Application of 8, 16 and 24 kg ha^{-1} Zn increased P uptake by the grain from 22.98 kg ha^{-1} at no Zn level to 29.29, 28.9 and 27.84 kg ha^{-1} , respectively (27.46, 25.76 and 21.14 percent



increase, in that order), but there was no significant difference between these levels.

Table 5. The effect of Zn and B on P uptake by the grain (kg ha⁻¹)*

B levels (kg ha ⁻¹)	Zn levels (kg ha ⁻¹)				Foliar Spray	Mean of B levels
	0	8	16	24		
0	21.58 ef	27.65 abcdef	23 cdef	22.12 def	26.4 abcdef	24.15 b
3	26.9 abcdef	30.7 abcd	28.01 abcdef	32.06 ab	27.99 abcdef	29.13 a
6	22.07 def	28.24 abcdef	34.36 a	25.67 abcdef	26.08 abcdef	27.28 ab
Foliar Spray	21.36 f	30.56 abcd	30.25 abcde	31.5 abc	24.5 bcdef	27.63 a
Mean of Zn levels	22.98 b	29.29 a	28.9 a	27.84 a	26.24 ab	

*The same letters are not significantly different in each row or in each column at 5% level by Duncan's test

Also, the main effect of B on the P uptake by the grain (kg ha⁻¹) was significant at the 5% level (Table 5). The least mean P uptake by the grain, 24.15 kg ha⁻¹, was seen at no B level. Boron application at 3 kg ha⁻¹, significantly increased P uptake by the grain from 24.15 to 29.13 kg ha⁻¹, showing an increase of 20.62% as compared with the no B level. The highest P uptake by the grain was seen at 3 kg ha⁻¹ B level. Application of 3 kg ha⁻¹ B had no significant effect on the P uptake by the grain as compared with the 0 and 3 kg ha⁻¹ B levels. Boron spraying significantly increased P uptake by the grain, to 27.63 kg ha⁻¹, showing a 14.42 percent increase relative to the no B level, but showed no significant difference from when B was applied to the soil.

In analysis of Zn and B interaction affecting the P uptake by the grain it was seen that B use at high Zn levels (16 and 24 kg ha⁻¹ Zn) increased P uptake by the grain, but at low levels (0 and 8 kg ha⁻¹ Zn) and Zn spraying, B use had no significant effect on the P uptake by the grain. At 16 kg ha⁻¹ Zn, only application of 6 kg ha⁻¹ B increased P uptake by the grain from 23 to 34.36 kg ha⁻¹ (49.39% increase). Application of 3 kg ha⁻¹ B at 24 kg ha⁻¹ Zn level, increased the P uptake by the grain from 22.12 to 32.06 kg ha⁻¹ (44.94% increase as compared with no B use at this Zn level). Also, B spraying at 24 kg ha⁻¹ Zn, significantly increased P uptake by the grain, from 22.12 to 31.5 kg ha⁻¹ (42.4% increase), but showed no significant difference as compared with the 3 kg ha⁻¹ B level.

Zinc application at low B levels (0 and 3 kg ha⁻¹ B), had no significant effect on the P uptake by the grain, but at high B level (6 kg ha⁻¹) and B spraying level, increased P uptake by the grain. Application of 16 kg ha⁻¹ Zn at 6 kg ha⁻¹ B level, increased P uptake by the grain from 22.07 to 34.36 kg ha⁻¹ (55.68% increase), while other levels of Zn had no significant effect. At B spraying level, Zn application to the soil at all levels, increased P uptake by the grain, while Zn spraying had no significant effect. Application of 8, 16 and 24 kg ha⁻¹ Zn at B spraying level, increased P uptake by the grain from 21.36 to 30.56, 30.25 and 31.5 kg ha⁻¹, respectively (43.07, 41.61 and

47.47 percent increase as compared with no Zn use at this B level), but there was no significant difference between these levels.

The highest P uptake by the grain, 34.36 kg ha⁻¹, was obtained by joint use of 16 kg ha⁻¹ Zn and 6 kg ha⁻¹ B, showed 59.22% increase as compared with 21.58 kg ha⁻¹ of the control. There was no significant difference between lowest P uptake by the grain (21.36 kg ha⁻¹) and control.

Potassium concentration in the grain

The effect of application of different Zn levels on the K concentration in the grain (%) was insignificant at 5% level relative to no Zn level, but application of 24 kg ha⁻¹ Zn decreased grain K content as compared with 8 kg ha⁻¹ Zn level (Table 6). The highest grain K content, 0.47%, was seen at 8 kg ha⁻¹ Zn level but showed no significant difference from the zero Zn level. Also, the main effect of B on the grain K content was insignificant at 5% level.

Table 6. The effect of Zn and B on K concentration in the grain (%)*

B levels (kg ha ⁻¹)	Zn levels (kg ha ⁻¹)				Foliar Spray	Mean of B levels
	0	8	16	24		
0	0.42 cd	0.45 abc	0.45 abc	0.42 cd	0.45 abc	0.44 a
3	0.46 abc	0.45 abc	0.42 cd	0.45 abc	0.45 abc	0.45 a
6	0.44 bc	0.50 a	0.44 bc	0.49 ab	0.42 cd	0.46 a
Foliar Spray	0.45 abc	0.46 abc	0.46 abc	0.38 d	0.46 abc	0.44 a
Mean of Zn levels	0.44 ab	0.47 a	0.44 ab	0.44 b	0.45 ab	

The same letters are not significantly different in each row or in each column at 5% level by Duncan's test

The Zn-B interaction effect on the grain K content was significant at 1% level. Boron application at 6 kg ha⁻¹ B at a high Zn level (24 kg ha⁻¹ Zn) increased K concentration in the grain from 0.42 to 0.49% (13.64 percent increase as compared with no B use at this Zn level); however, at other Zn levels, B use showed no significant effect on the grain K content. Zinc application at 8 kg ha⁻¹ Zn at a high B level (6 kg ha⁻¹ B), made the maximum grain K content: 0.5%, (13.64 percent increase as compared with the no Zn use at this B level), a 19.05% increase relative to the control, with a grain K content of 0.42%. Application of 24 kg ha⁻¹ Zn at B spraying level, decreased K concentration in the grain from 0.45 to 0.38% (The least K concentration in the grain); showing a 15.15 percent decrease as compared with the no Zn use at this B level and showing a 9.52 percent decrease as compared with the control but this decrease was insignificant. At low B levels (0 and 3 kg ha⁻¹ B), Zn application showed no significant effect on the grain K content.

The highest and the lowest K concentration in the grain, 0.38 and 0.50%, was obtained by the use of 24 kg ha⁻¹ Zn + B spraying and 8 kg ha⁻¹ Zn + 6 kg ha⁻¹ B,



respectively; but there was no significant difference between the lowest K concentration in the grain and the control.

Studies made on wheat showed that by decrease in wheat grain Zn content, the grain K content decreased significantly (Ming & Yin, 1992; Rengel & Graham, 1995). Because in this research Zn application had no significant effect on the grain Zn content thus Zn use showed no significant effect on the grain K content.

Table 7. The effect of Zn and B on K uptake by the grain (kg ha⁻¹)*

B levels (kg ha ⁻¹)	Zn levels (kg ha ⁻¹)				Foliar Spray	Mean of B levels
	0	8	16	24		
0	28.36 d	38.75 abc	34.38 abcd	32.94 bcd	39.85 abc	34.86 b
3	37.62 abcd	40.8 abc	38.22 abcd	41.62 abc	39.23 abc	39.5 a
6	31.96 cd	43.49 a	42.47 ab	39.76 abc	37.59 abcd	39.06 a
Foliar Spray	34.15 bcd	39.65 abc	44.82 a	39.34 abc	38.74 abc	39.34 a
Mean of Zn levels	32.02 b	40.67 a	39.97 a	38.42 a	38.85 a	

*The same letters are not significantly different in each row or in each column at 5% level by Duncan's test

Potassium uptake by the grain

The main effect of Zn on the K uptake by the grain (kg ha⁻¹) was significant at the 1% level (Table 7). Zinc application at all levels, significantly increased K uptake by the grain relative to the no Zn level. The least K uptake by the grain, 33.02 kg ha⁻¹, was seen at zero Zn level. Application of 8, 16 and 24 kg ha⁻¹ Zn, increased K uptake by the grain from 33.02 kg ha⁻¹ at zero Zn level to 40.67, 39.97 and 38.42 kg ha⁻¹, respectively (23.17, 21.05 and 16.35 percent increase relative to no Zn level); but there was no significant difference between levels of Zn added to the soil. Also, Zn spraying increased K uptake by the grain from 33.02 to 38.85 kg ha⁻¹ (17.65% increase relative to no Zn level) but there was no significant difference at application to the soil levels.

Also, application of difference B levels on the K uptake by the grain was significant at 5% level. The least mean K uptake by the grain, 34.86 kg ha⁻¹, was seen at no B level. The use of 3 and 6 kg ha⁻¹ B, significantly increased K uptake by the grain from 34.86 to 39.5 and 39.06 kg ha⁻¹, respectively (13.31 and 12.05 percent increase relative to the no B level); but there was no significant difference between levels of Zn added to the soil. Also B spraying significantly increased K uptake by the grain to 39.34 kg ha⁻¹ (12.85% increase as compared with the no B level) there was no significant difference from that of B being added to the soil.

In analysis of Zn and B interaction affecting the K uptake by the grain it was seen that B use had no significant effect on the K uptake by the grain in any levels of Zn. Zinc application at 3 kg ha⁻¹ B level, showed no significant on the K uptake by the grain, while at other B levels, increased K uptake by the grain. At zero B level, the use of 8 kg ha⁻¹ Zn and Zn spraying increased K

uptake by the grain from 28.36 to 38.75 and 39.85 kg ha⁻¹, respectively (36.64 and 40.51 percent increase as compared with the no Zn use at this B level), while other levels of Zn had no significant effect. The use of 16 and 24 kg ha⁻¹ Zn at 3 kg ha⁻¹ B level, significantly increased K uptake by the grain from 31.96 to 43.49 and 42.47 kg ha⁻¹, respectively (36.07 and 32.88 percent increase relative to no Zn use at this B level), while other levels of Zn had no significant effect. At Zn spraying level, only application of 16 kg ha⁻¹ Zn made the maximum increase in K uptake by the grain, 44.82 kg ha⁻¹, showing a 31.24% increase relative to the no Zn level at this B level and a 58.04% increase as compared with the control with an uptake of 28.36 kg ha⁻¹. The least K uptake by the grain, 28.36 kg ha⁻¹, was observed due to nonuse of Zn and B (the control treatment)

Correlation between the concentration and total uptake of N, P and K in grain with other variables

Concentration and uptake and other variables, correlation coefficients (R) and (R²) between different variables were computed using the Pearson method and equations relating to each variable were derived using the step-by-step method. The symbols * and ** in equations denote significance at 5 percent level ($\alpha = 0.05$) and 1 percent level ($\alpha = 0.01$) respectively.

Nitrogen concentration in the grain

The grain N content showed a positive correlation with the leaf K content (R= 0.38), Fe (R= 0.32), Zn (R= 0.31) and B (R= 0.47), the grain B content (R= 0.43), the uptake of N (R= 0.67**) and B (R= 0.42) by the grain, the percentage of grain in the ear (R= 0.40) and grain protein content (R= 0.99**) and a negative correlation with the leaf N content (R= -0.38) and P (R= -0.33), the grain Cu content (R= -0.32), the ear length (R= -0.33), the ear diameter (R= -0.40) and 1000-grain weight (R= -0.38). The equations of which were:

- 1) NG = - 0.00144 + 0.176 P R = 1**
- 2) NG = - 0.00186 + 0.176 P - 0.00000945 BUG R = 1**
- 3) NG = 0.00408 + 0.176 P - 0.0000143 BUG + 0.0000496 NGL R = 1**

NG, P, BUG and NGL are N grain content (%), grain protein content (%), B uptake by the grain (g ha⁻¹) and number of grains in the ear length, respectively.

Nitrogen uptake by the grain

There was a positive correlation between N uptake by the grain and the leaf Zn content (0.41), the grain N content (0.67**), P content (R= 0.33), Mn content (0.38) and B content (0.53), the uptake of P (0.79**), K (0.78**), Fe (0.31), Mn (0.63**), Zn (0.56**), Cu (0.31) and B (0.76**), ear weight (0.68**), grain weigh in the ear (0.69**), total grain yield (0.88**), the number of grains in the ear length (0.58**), the number of grains across the ear diameter (0.31), grain protein content (0.67**), and a negative correlation with leaf Mn content (-0.32) and Cu content (-0.33). The equations of which were:

- 1) NUG = -22.417 + 0.0197 TGY R = 0.882**

- 2) $NUG = -145.955 + 0.017 TGY + 86.073 NG$ $R^2 = 0.998^{**}$
 3) $NUG = -146.408 + 0.0171 TGY + 83.816 NG + 4.847 CuS$ $R^2 = 0.999^{**}$
 4) $NUG = -139.577 + 0.0172 TGY + 81.666 NG + 6.573 CuS - 0.000374 DM$ $R^2 = 0.999^{**}$

NUG, TGY, NG, CuS and DM denote N uptake by the grain ($kg\ ha^{-1}$), total grain yield ($kg\ ha^{-1}$), grain N content (%), soil Cu content after harvest ($mg\ kg^{-1}$) and dry matter ($kg\ ha^{-1}$), respectively.

The grain P content

The grain P content showed a positive correlation with the grain Fe content ($R = 0.35$), Mn content (0.35) and B content ($R = 0.58^{**}$), the grain's uptake of N ($R = 0.33$), P ($R = 0.74^{**}$), K ($R = 0.46$), Fe ($R = 0.48$), Mn ($R = 0.43$) and B ($R = 0.58^{**}$), total grain yield ($R = 0.33$). The relevant equations were:

- 1) $PG = 0.201 + 0.00421 PUG$ $R = 0.74^{**}$
 2) $PG = 0.311 + 0.0113 PUG - 0.000035 TGY$ $R^2 = 0.99^{**}$

PG, PUG and TGY are P concentration in the grain (%), P uptake by the grain ($kg\ ha^{-1}$) and total grain yield ($kg\ ha^{-1}$), respectively.

The grain K content

There was a positive correlation between grain K content and leaf Fe content ($R = 0.58^{**}$), Cu content ($R = 0.32$) and the uptake of K by the grain ($R = 0.42$), and a negative correlation with grain Cu content ($R = -0.35$), Cu uptake by the grain ($R = -0.40$) and ear diameter ($R = -0.50$). The equations were:

- 1) $KG = 0.285 + 0.00143 FeL$ $R = 0.58^{**}$
 2) $KG = 0.193 + 0.00139 FeL + 0.0025 KUG$ $R^2 = 0.50^{**}$
 3) $KG = 0.423 + 0.0000557 FeL + 0.0109 KUG - 0.000467 TGY$ $R^2 = 0.99^{**}$
 4) $KG = 0.43 + 0.0111 KUG - 0.000475 TGY$ $R^2 = 0.99^{**}$
 5) $KG = 0.41 + 0.0111 KUG - 0.000477 TGY + 0.00885 KL$ $R^2 = 0.99^{**}$
 6) $KG = 0.391 + 0.0111 KUG - 0.000481 TGY + 0.00924 KL + 0.00119EL$ $R^2 = 0.99^{**}$

KG, FeL, KL, KUG and EL are grain K content (%), leaf Fe content ($mg\ kg^{-1}$) and K content (%), K uptake by the grain ($kg\ ha^{-1}$) and ear length (cm), respectively.

The P uptake by the grain

The P uptake by the grain showed a positive correlation with the grain P content ($R = 0.74^{**}$), Mn content ($R = 0.52$) and B content ($R = 0.60$), the uptake of N ($R = 0.79^{**}$), K ($R = 0.82^{**}$), Fe ($R = 0.49$), Mn ($R = 0.73^{**}$), Zn ($R = 0.56^{**}$), Cu ($R = 0.36$) and B ($R = 0.82^{**}$) by the grain, ear weight ($R = 0.64$), grain weight in the ear ($R = 0.60$), total grain yield ($R = 0.88^{**}$) and the number of grains in the ear length ($R = 0.67$) and a negative correlation with the grain Fe content ($R = -0.32$). The relevant equations were:

- 1) $PUG = -5.84 + 0.00384 TGY$ $R = 0.88^{**}$
 2) $PUG = -27.316 + 0.00312 TGY + 87.77 PG$ $R^2 = 0.99^{**}$
 3) $PUG = -25.836 + 0.00313 TGY + 86.653PG - 0.528 KL$ $R^2 = 0.99^{**}$
 4) $PUG = -23.928 + 0.0031 TGY + 86.758PG - 0.783 KL - 0.164 CuL$ $R^2 = 0.99^{**}$

- 5) $PUG = -23.817 + 0.00307 TGY + 86.023 PG - 0.777 KL - 0.161 CuL + 0.0798 MnG$ $R^2 = 0.99^{**}$
 6) $PUG = -24.358 + 0.00309 TGY + 84.98 PG - 0.856 KL - 0.193 CuL + 0.0783 MnG + 2.542 KG$ $R^2 = 0.99^{**}$
 CuL and MnG are Leaf Cu content ($mg\ kg^{-1}$) and grain Mn content ($mg\ kg^{-1}$), respectively.

The K uptake by the grain

There was a positive correlation between K uptake by the grain and grain P content ($R = 0.46$), K content ($R = 0.41$), Mn content ($R = 0.41$) and B content ($R = 0.47$), the uptake of N ($R = 0.78$), P ($R = 0.82^{**}$), Mn ($R = 0.61$), Zn ($R = 0.63^{**}$) and B ($R = 0.68^{**}$) by the grain, ear weight ($R = 0.52$), grain weight in the ear ($R = 0.49$), total grain yield ($R = 0.83^{**}$) and the number of grains in the ear length ($R = 0.70$) and a negative correlation with the ear diameter ($R = -0.42$). The equations were:

- 1) $KUG = 5.064 + 0.00387 TGY$ $R = 0.83^{**}$
 2) $KUG = -38.316 + 0.00428 TGY + 89.234 KG$ $R^2 = 0.99^{**}$
 3) $KUG = -36.47 + 0.00429 TGY + 89.182 KG - 0.797 KL$ $R^2 = 0.99^{**}$
 4) $KUG = -34.867 + 0.00431 TGY + 89.237 KG - 0.831 KL - 0.107 EL$ $R^2 = 0.99^{**}$

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