Application of Different Levels of Zinc and Boron on Concentration and Uptake of Zinc and Boron in the Corn Grain

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Abstract: For the purpose of studying the effect of Zn and B application on the concentration and total uptake of Zn and B in corn grain, a field experiment was conducted in Fars Province, Iran. Treatments including five levels of Zn (0, 8, 16 and 24 kg ha^{-1} and Zn foliar spray) and four levels of B (0, 3, and 6 kg ha^{-1} and B foliar spray) in a completely randomized block design were set up. The findings showed that the presence of Zn prevented from the increase in Zn concentration in the grain, by B application; while B applied in the presence of Zn had no effect on the amount of Zn uptake by the grain. At the level that lacked B, Zn use increased Zn concentration and uptake in the grain but at the levels where B was used, the presence of B prevented from the effect of Zn application on the Zn concentration and uptake in the grain. The minimum concentration and uptake of Zn in the grain was observed by lack of Zn and B use or the control treatment. Therefore, an antagonism between Zn and B was observed as regards concentration and uptake of Zn in the grain. At the highest Zn level, the B use caused an increase in concentration and uptake of B in the grain. Also, at the high B level, application of Zn caused an increase in the B concentration in the grain. Boron use at low levels and Zn solution spray, had no effect on the uptake of B in the grain, but at high B levels, it increased the B uptake in the grain. Therefore, the presence of a high amount of Zn or B in the soil, assisted in the effect of B or Zn on increasing concentration and uptake of B in the plant. That is, a synergism was seen between the Zn and B as effecting the concentration and uptake of B in the grain. [Journal of American Science 2010; 6(5):100-106]. (ISSN: 1545-1003).

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1. 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). 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). 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 and Walker, 1993). Corn is among the plants most sensitive to Zn deficiency. The amount of Zn uptake from the soil is 130 gr for each metric ton of corn grain (Tandon, 1995). If the harvest of the corn grain is 9.5 metric tons per ha, the Zn uptake by the plant would be 10 kg ha^{-1} (Marschner, 1995). 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). Singh et al. (1990) reported that B application increased its concentration and uptake in wheat and the same increased when Zn was not used. Moreover, when B was not used, application of Zn reduced B concentration and uptake in the plant. Adding B to the soil caused a low effect by Zn application on B concentration and uptake. A large number of authors have reported that using Zn increased its concentration in the plant (Gupta and Singh, 1985; Darajeh et al, 1991; Karimian and Yasrebi, 1995). 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. Massey et al. (1996) while studying the Zn concentration in the grain observed that the least and the highest Zn concentration in the grain were 15.5 and 38.4 mg kg^{-1}, respectively.

The increase of B concentration in the plant using B is reported by some authors (Grant and Baily, 1990; Wei et al., 1996; Hu and Brown, 1997).

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 Zn and B elements plays an effective role in human health. Also, richness of the grain in these elements reflects quantitative and qualitative increase in the grain harvest. Therefore, by studying Zn-B interaction in the grain, we can enrich the grain while understanding its indirect effects which are quantitative and qualitative improvement in the grain harvest. Moreover, it is an established fact that if grains rich in these elements are used as seeds, the harvest will improve quantitatively and qualitatively.

2. Materials and Methods

A field experiment was conducted at the farm Aref in Abadeh Tashk, Fars province, Iran, on the corn (*Zea mays L.*), cultivar "Single Cross 401" during 2009 cropping season. The area is located in northeast of Shiraz, with latitude 29° 44' 40.9" N and longitude 53° 53' 44.9" E. This experiment included 20 treatments and 3 replications in the form of completely randomized block design and factorial that combinations of five levels Zn (0, 8, 16 and 24 kg ha^{-1} Zn, and Zn foliar spray) and four levels of B (0, 3, and 6 kg ha^{-1} and B, and B foliar spray). Nitrogen: P: K used at 180, 70 and 75 kg ha^{-1} according to the recommendation, from sources of urea (46% N), triple super phosphate (46% P_2O_5) and potassium sulfate (50% K_2O), respectively, were added to all treatments (plots). Moreover, 50% of the urea was used when planting and the remainder two times: At vegetative growth (35 days after planting) 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 5 per thousand (0.5%) Zn sulfate and 3 per thousand (0.3%) B 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 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, dry matter and the residual available phosphorus and Zn in the soil after corn harvest were measured.

Analysis of the grain and the soil was carried out using common lab procedures (Soil and Plant Analysis Council, 2004). Phosphorous was measured by Olsen method, available potassium by Ammonium Acetate extraction method and potassium assessment in the extract by flame photometer, organic carbon by the Walkley and Black method. Available Fe, Zn, Mn and Cu in the soil were first extracted by DTPA and then were read by atomic absorption. The soil's available B was extracted by hot water and then was measured by spectrophotometer by curcamin method, considering the intensity of the color produced. Digestion method by dry burning was used to measure Zn and then was measured by atomic absorption setup. Statistical analysis of data was made using SAS software with Duncan test and regression equations via the SPSS program.

3. Results and Discussion

The results of soil analysis before plantation are presented in table 1. The soil available P was lower but the soil available K was higher than the critical level suggested in scientific sources (Rashid et al., 1994; Karimian and Yasrebi, 1995). Karimian and Ghanbari (1990) have reported that the critical P level by the Olsen method in calcareous soils as 18 mg kg^{-1}. The soil available Zn, B, Fe and Cu was low but the Mn was above 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. Agrawala (1992), reports the critical levels of Fe, Zn, Mn and Cu in soil with DTPA extractor as 2.5, 0.8, 5.5 and 0.78 mg kg^{-1} soil, respectively.

Table 1.The result of soil analysis

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

3.1. The grain Zn content

The main effect of Zn on the grain Zn content (mg kg^{-1}) was insignificant at the 5% level (table 2). Boron application in spray form led into a significant reduction in grain Zn content from 28.47 to 24.27 mg kg^{-1} (14.75 percent reduction as compared with zero B level). However, adding B to the soil had no significant effect on the grain Zn content. The highest and the lowest mean grain Zn content at 28.47 and 24.27 mg kg^{-1} levels were seen at zero B level and B spraying level. Therefore, a negative interaction was seen between B application in spray form and grain Zn content.

In analysis of Zn and B interaction affecting the grain Zn contents it was seen that B application at 16 kg ha^{-1} Zn reduced grain Zn content but at other Zn levels, it had no significant effect on Zn content. Application of 3 kg ha^{-1} and spraying B at 16 kg ha^{-1} Zn reduced grain Zn content from 35.67 to 24.67 and 23.76 mg kg^{-1}, respectively (30.83 and 33.64 percent reduction) but application of 6 kg ha^{-1} B had no significant effect. At zero B level, only the use of 16 kg ha^{-1} Zn significantly increased grain Zn content from 20.67 to 35.67 mg kg^{-1} (72.56% increase). But at high levels (3 and 6 kg ha^{-1} B) and B spraying, Zn application had no effect on grain Zn content. In fact, B use as added to soil or sprayed, prevented from application of B to affect grain Zn content. The least grain Zn content at 2.67 mg kg^{-1}, was observed due to nonuse of Zn and B (the control treatment). The highest grain Zn content, at 35.67 mg kg^{-1} was obtained by applying 16 kg ha^{-1} Zn, showing an increase of 72.56% as compared with the control. Except the treatment with the highest grain Zn content, the treatments showed no significant difference from the control.

Increase in corn grain Zn content by Zn application has been reported by different authors (Victor et al., 1990; Grewal et al., 1997; Sugreeve et al., 1998; Singh and Verma, 1999). According to Massey and Loeffel (1996), grain Zn content was at least 15.5 and at most 38.4 mg kg^{-1}. In this study, the grain Zn content in the control treatment was 20.67 mg kg^{-1}, which is higher than the minimum suggested.

Table 2. The effect of Zn and B on Zn concentration in the grain (mg kg^{-1})

B (kg ha^{-1})	Zn (kg ha^{-1}) 0	8	16	24	Foliar Spray	Mean
0	20.67 b	30 ab	35.67 a	28 ab	28 ab	28.47 a
3	24.67 b	27.67 ab	24.67 b	28.67 ab	26.67 ab	26.57 ab
6	23.33 b	25.67 ab	27.33 ab	26 ab	27 ab	25.87 ab
Foliar Spray	25 b	23 b	23.67 b	22.33 b	27.33 ab	24.27 b
Mean	23.42 a	26.58 a	27.83 a	26.25 a	27.25 a	

3.2. Zinc uptake by the grain

The effect of application of different B levels on Zn uptake by the grain (g ha^{-1}), was insignificant at 5% level, but the main effect on Zn uptake was significant at 1% level (table 3). The least mean Zn uptake by the grain, 174.77 g ha^{-1}, was seen at zero Zn level and Zn application at all levels (to the soil and spraying), significantly increased Zn uptake by the grain. Application of 8, 16 and 24 kg ha^{-1} Zn, increased Zn uptake by the grain from 174.77 g ha^{-1} at no Zn level to 233.73, 246.36 and 230.12 g ha^{-1}, respectively (33.73, 40.96 and 31.67 percent increase, in that order). But there was no significant difference between levels of Zn added to the soil. Zinc spraying significantly increased Zn uptake by the grain to 238.47 g ha^{-1} (36.44 percent increase as compared with the no Zn level), while there was no significant difference from that of Zn being added to the soil. The effect of Zn-B interaction on the Zn uptake by the grain showed that B application in any Zn level had no significant effect on Zn uptake by the grain. Zinc use at no B level increased Zn uptake by the grain, but at other levels of B it had no significant effect on the Zn uptake. Application of Zn at 8 and 16 kg ha^{-1} Zn levels at no B level, significantly increased Zn uptake by the grain from 139.4 g ha^{-1}, to 258.9 and 269.73 g ha^{-1}, respectively (85.72 and 93.49 percent increase relative to no Zn use at the level of B). Zinc spraying at no B level, increased Zn uptake by the grain from 39.4 to 247.8 g ha^{-1} (77.76% increase), but it had no significant difference from when Zn was applied to the soil. Probably the antagonism between Zn and B, applying B to the soil or spraying, prevented from an increase in Zn uptake by the grain, by the Zn application. The least and the most Zn uptake by the grain, 139.4 and 269.73 (93.49% increase relative to the control) (g ha^{-1}), were observed in the control treatment (no Zn and B use) and 16 kg ha^{-1} Zn, respectively.

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

B (kg ha^{-1})	Zn (kg ha^{-1})					
	0	8	16	24	Foliar Spray	Mean
0	139.4 c	30 ab	258.9 ab	216.1 abc	247.8 ab	226.39 a
3	202.63 abc	254.23 ab	222.33 abc	263.83 ab	234.63 abc	235.53 a
6	168.47 bc	222.27 abc	263.2 ab	211.17 abc	244.1 ab	221.84 a
Foliar Spray	188.57 abc	199.5 abc	230.17 abc	229.37 abc	227.33 abc	214.99 a
Mean	174.77 B	233.73 a	246.36 a	230.12 a	238.47 a	

3.3. The grain B content

The main effect of Zn on Grain B content (mg kg^{-1}) was not significant at 5% level, but application of different levels of B was significant at 5% level (table 4). The least and the most mean grain B content, 7.94 and 10.49 mg kg^{-1}, were observed at no B level and 6 kg ha^{-1} B. The use of 3 and 6 kg ha^{-1} B, significantly increased B concentration in the grain from 7.94 mg kg^{-1} at no B level, to 9.38 and 40.49 mg kg^{-1}, respectively (33.8 and 32.11 percent increase, in that order), but there was no significant difference between these two B levels. Boron spraying showed no significant difference with no B level and adding B to the soil. Examination of the Zn-B interaction showed that at high Zn level (24 kg ha^{-1} Zn), only the increase of 3 kg ha^{-1} in B increased the grain B content from 6.04 to 12.12 mg kg^{-1} (100.66% increase). However, at other Zn levels, B use showed no significant effect on grain B content. Zinc application at 16 kg ha^{-1} Zn at a high B level (6 kg ha^{-1} B), increased grain B content from 9.13 to 13.93 mg kg^{-1} (52.57% increase), while other levels of Zn had no significant effect. At low levels (zero and 3 kg ha^{-1} B) and B spraying, Zn use had no significant effect on the grain B content. Except for the treatment with the highest grain B content, all treatments showed no significant difference from the control. Joint use of 16 kg ha^{-1} Zn and 6 kg ha^{-1} B, made the maximum grain content: 13.93 mg kg^{-1}, a 68.44% increase relative to the control 8.27 mg kg^{-1}. Increase in wheat grain boron content by application of B has been reported by Singh et al. (1990), Singh and Singh (1980) and Shen et al (1998).

Table 4. The effect of Zn and B on B concentration in the grain (mg kg^{-1})

B (kg ha^{-1})	Zn (kg ha^{-1})					
	0	8	16	24	Foliar Spray	Mean
0	8.27 bcd	8.88 bcd	9.43 abcd	6.04 d	7.1 cd	7.94 b
3	8.53 bcd	9.13 bcd	8.4 bcd	12.12 ab	10.93 abc	9.83 a
6	9.13 bcd	10.54 abcd	13.93 a	9.33 abcd	9.5 abcd	10.49 a
Foliar Spray	9.37 abcd	9.07 bcd	9 bcd	9.83 abcd	9.77 abcd	9.41 ab
Mean	8.83 a	9.41 a	10.19 a	9.33 a	9.33 a	

3.4. Boron uptake by the grain

Among different levels of Zn, application of 16 kg ha^{-1} Zn significantly increase B uptake by the grain (g ha^{-1}) relative to no Zn level (positive Zn-B interaction), while other levels of Zn had no significant effect on B uptake (table 5). The least mean B uptake by the grain, 65.47 g ha^{-1} was seen at no Zn level. The highest mean B uptake by the grain, 92.37 g ha^{-1}, was seen at 16 kg ha^{-1} Zn, a 40.72% increase as compared with no Zn level.

The main effect of B on B uptake by the grain was significant at 5% level. The lowest and the highest mean B uptake by the grain, 63.13 and 90.49 g ha^{-1}, were seen at no B level and 6 kg ha^{-1} B. Boron application at all levels, significantly increased B uptake by the grain relative to the no B level. The use of 3 and 6 kg ha^{-1} B, significantly increased B uptake by the grain from 63.13 at no B level, to 86.95 and 90.49 g ha^{-1}, respectively (37.73 and 43.34 percent increase) but there was no significant difference between those two B levels. Boron spraying significantly increased B uptake by the grain, to 83.53 g ha^{-1}, showing a 32.31 percent increase relative to the no B level, but showed no significant difference from when B was applied to the soil.

Table 5. The effect of Zn and B on B uptake by the grain (g ha^{-1})

B ($kg\ ha^{-1}$)	Zn ($kg\ ha^{-1}$)					
	0	8	16	24	Foliar Spray	Mean
0	55.87 cd	263 bcd	71.67 bcd	46.7 d	65.1 bcd	63.13 b
3	70 bcd	82.13 bcd	75.23 bcd	112.5 ab	94.87 abcd	86.95 a
6	65.9 bcd	91.53 abcd	134.67 a	76.1 bcd	84.27 bcd	90.49 a
Foliar Spray	70.8 bcd	76.77 bcd	78.9 bcd	100.97 abc	81.23 bcd	83.53 a
Mean	65.64 b	81.86 ab	92.37 a	84.07 ab	81.37 ab	

The effect of Zn-B interaction on B uptake by the grain showed B application at low levels (zero and 8 kg ha^{-1} Zn), and Zn spraying had no effect on B uptake by the grain, while at high Zn levels (16 and 24 kg ha^{-1} Zn), increased B uptake by the grain. At 16 kg ha^{-1} Zn, only application of 6 kg ha^{-1} B increased B uptake by the grain from 71.67 to 34.67 g ha^{-1} (87.9% increase). Application of 3 kg ha^{-1} and spraying of B at high Zn level (24 kg ha^{-1} sulfate) increased B uptake by the grain from 46.7 to 112.5 and 100.97 g ha^{-1}, respectively (140.9 and 116.2% increase), while using 6 kg ha^{-1} B had no significant effect. At 6 kg ha^{-1} B, only the use of 16 kg ha^{-1} Zn significantly increased B uptake by the grain from 65.9 to 134.67 g ha^{-1} (104.35% increase). But at other B levels, Zn application had no significant effect on B uptake by the grain. No treatment, except the treatment with the highest B uptake by the grain, showed a significant difference from the control. The highest B uptake by the grain, 134.67 g ha^{-1}, was obtained by the joint use of 6 kg ha^{-1} B and 16 kg ha^{-1} Zn, a 141% increase relative to the control, with an uptake of 55.87 g ha^{-1}.

Singh et al. (1990) observed that by B application, its concentration and uptake in the grain increased, and that increase was higher when a Zn deficiency prevailed. With increasing the B level, Zn application decreased B concentration and total B uptake.

3.5. Concentration and uptake of Zn and B in grain with other variables

Concentration and uptake and other variables, correlation coefficients (R) and (R^2) 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.

3.6. The grain Zn content

The grain Zn content showed a positive correlation with leaf P content (R= 0.5^{*}), Mn content (R= 0.57^{*}), and Zn content (R= 0.42), grain Mn content (R= 0.49^{*}), grain's Mn (R= 0.35), and Zn (R= 0.76^{*}) uptake and the number of grain along the corn ear (R= 0.35) and a negative correlation with leaf B content (R= -0.4), % of grains in the ear (R= -0.33) and the dry matter (R= -0.36). The equation of which was: ZnG = 27.624 + 0.182 ZnUG - 0.00323 TGY - 0.0223 FeG + 0.141 ZnS + 0.0769 PS + 0.0000985 DM R^2= 0.998* ZnG, ZnUG, TGY, FeS, ZnS, PS and DM denote grain Zn content (mg kg^{-1}), Zn uptake by the grain (g ha^{-1}), total grain harvest (kg ha^{-1}), grain Fe content (mg kg^{-1}), soil Fe content after harvest (mg kg^{-1}), soil Zn content after harvest (mg kg^{-1}), soil P content after harvest (mg kg^{-1}) and dry matter (mg ha^{-1}).

3.7. The Zn uptake by the grain

There was a positive correlation between Zn uptake by the grain and the leaf P content (R= 0.57^{**}), Zn content (R= 0.56^{**}), the grain Mn content (R= 0.71^{**}), Zn content (R= 0.76^{**})and B content (R= 0.73), the grain's uptake of N (R= 0.56^{**}), P (R= 0.56^{**}), K (R= 0.63^{**}), Fe (R= 0.35), Mn (R= 0.76^{**}), Cu (R= 0.39) and B (R= 0.54^{*}), ear's weight (R= 0.36), grain weight in the ear (R= 0.32), total grain harvest (R= 0.63^{**}), number of grains along the ear (R= 0.45^{*}), number of grains across the ear diameter (R= 0.5^{*}) and a negative correlation with leaf B content (R= -0.4) and the ear diameter (R= -0.3). The relevant equation was ZnUG = -214.814 + 8.155 ZnG + 0.0255 TGY + 0.0197 FeUG - 1.14 ZnS -0.66PS + 0.000781 DM R^2= 0.999*

3.8. The grain B content

The grain B content showed a positive correlation with the grain N content (R= 0.43), P content (R= 0.58^{**}) and Mn content (R= 0.61^{**}), the grains' uptake of N (R= 0.53^{*}), P (R= 0.6^{**}), K (R= 0.47^{*}), Fe (R= 0.45^{*}), Mn (R= 0.66^{**}), Zn (R= 0.37) and B (R= 0.92^{**}), ear weight (R= 0.48^{*}), grain weight in the ear (R= 0.48*), total grain harvest (R= 0.41), the number of grains in the ear length (R= 0.42), the number of grains across the ear diameter (R= 0.32) and grain protein content (R= 0.43) and a negative correlation with leaf N content (R= -0.41), Mn content (R= -0.43), and Cu content (R= -0.38).

BG = 0.114 + 0.11 BUG - 0.00101 TGY R^2= 0.989**

BG, BUG and TGY are grain B content (mg kg^{-1}), B uptake by the grain (g ha^{-1}) and total grain harvest (kg ha^{-1}), respectively.

3.9. The B uptake by the grain

There was a positive correlation between B uptake by the grain and the grain N content (R= 0.42), P content (R= 0.58*), Mn content (R= 0.66**) and B content (R= 0.92**), the grain N uptake (R= 0.76**), P uptake (R= 0.82**), K uptake (R= 0.68**), Fe uptake (R= 0.49*), Mn uptake (R= 0.8**) and Zn uptake (R= 0.54*), ear weight (R= 0.64**), grain weight in the ear (R= 0.65**), total grain harvest (R= 0.72**), the number of grain along the ear (R= 0.62**), the number of grains across the ear diameter (R= 0.43), and the grain protein content (R= 0.42) and a negative correlation with the leaf Mn content (R= -0.45*) and Cu content (R= -0.4).

BUG = -0.82.261 + 8.843 BG + 0.00924 TGY R^2= 0.994**

4. Conclusion

In conclusion, Zn application had no effect on the grain Zn and B contents, but application of Zn to the soil as well as Zn spraying increases Zn uptake by the grain. Boron spraying decreased the grain Zn content but B application to the soil had no effect on it. Boron application had no effect on the Zn uptake by the grain. Boron application to the soil increased grain B content, but B spraying had no effect on it. Also, B application to the soil and its spraying increased B uptake by the grain.

The presence of Zn prevents from grain Zn content increase by B application so that B use at 16 kg/ ha Zn, reduced grain Zn content. Also, application of B in the Zn presence had no effect on Zn uptake by the grain. At no B level, Zn application increased grain Zn content and uptake while at B use levels, the presence of B prevented from the effect of Zn application on the grain Zn content and uptake. The least grain Zn content and uptake was seen by no Zn and B application or in the control treatment. Therefore, an antagonism existed between Zn and B affecting grain Zn content and uptake.

At high Zn level (24 kg ha^{-1} Zn), B use increased grain B content; also at high B (6 kg ha^{-1} B) level, Zn application increased grain B content. Such an effect was seen for B uptake by the grain as well. Application of B at low levels (zero and 8 kg ha^{-1} Zn) and at Zn spraying level, had no effect on the B uptake by the grain but at high Zn levels (16 and 24 kg /ha Zn) it increased B uptake by the grain. Zinc use at high B level, increased B uptake by the grain but had no effect on it at other B levels. Therefore, a high soil B or Zn content, helped with the B or Zn effect on the increase in plant B content and uptake. That is, a synergism existed between B and Zn affecting grain B content and uptake. The Zn uptake by the grain was positively related with the leaf P and Zn contents, and negatively related with the leaf B content. The grain B content had a positive correlation with the grain N, P and Mn content, total grain harvest and grain protein content while it had a negative correlation with the leaf N, Mn and Cu content. Boron uptake by the grain was positively related with grain N, P, Mn and B contents and N, K, phosphorus, iron, Mn and Zn uptake by the grain, total grain harvest and grain protein and negatively related to the leaf Mn and Cu contents.

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