Zinc and Boron Fertilization on Concentration and Uptake of Iron and Manganese in the Corn Grain

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Abstract: A farm experiment with corn plant grown on Zn and B deficient soil was conducted to study the effect of Zn and B interaction on the concentration and total uptake of Fe and Mn in corn grain during 2009 at 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 effects of Zn and B and the interaction of Zn and B on the Fe concentration in the grain were insignificant. The effect of Zn on Fe uptake in the grain was insignificant and among different levels of B, only application of 3 kg ha^{-1} B increased Fe uptake in the grain. Boron use had no effect on Fe uptake in the grain in any level. Only at high level of B (6 kg ha^{-1} B), application of 16 kg ha^{-1} Zn increased Fe uptake in the grain. Boron use and Zn and B interaction was not significant on Mn concentration in the grain. Application of 24 kg ha^{-1} Zn increased Mn concentration in the grain from 3.67 to 4.75 mg kg^{-1} but other levels of Zn had no effect. Application of Zn to the soil and spraying it increased Mn uptake in the grain. Application of B to the soil increased Mn uptake in the grain but B spraying had no effect on it. Application of B at low levels and Zn spraying had no effect on Mn uptake in the grain but at higher Zn levels (16 and 24 kg ha^{-1} Zn) increased Mn uptake in the grain. Application of Zn at zero and 6 kg ha^{-1} B levels increased Mn uptake in the grain but at other B levels, it had no significant effect on Mn uptake. [Journal of American Science 2010;6(8):236-242]. (ISSN: 1545-1003).

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1. Introduction

Zinc deficiency is a very important nutrient problem in the world's soils. Total Zn concentration is in sufficient level in many agricultural areas, but available Zn concentration is in deficient level because of different soil and climatic conditions. Soil pH, lime content, organic matter amount, clay type and amount and the amount of applied P fertilizer affect the available Zn concentration in soil (Adiloglu et al., 2006). Zinc deficiency rate was determined as a 30 % in the world (Sillanpaa, 1982). The interaction among nutrient elements is very important for plant nutrition. Boron x Zn interaction among these interactions has been curicial in the Zn deficient soils, in recent years (Alkan et al., 1998). Plant root cell membrane permeability increases in Zn deficient soils[5], which may lead to accumulate B and other nutrient elements in plant roots. Therefore, excess B uptakes by plants may cause B toxicity for the plants in this soil conditions (Singh et al., 1990).

Zinc and Fe are antagonistic; of course this is not always the case and even in some cases they are combined and used, they can play a useful and effective role on plant growth and increase in the harvest (Baybordi et al., 2000; Haghnia et al., 1989). When the corn plant is under Zn stress, it absorbs a large amount of Fe and Mn, worsening the adverse effects of Zn deficiency (Tisdale et al., 1993; Warnocke et al., 1973). Moreover, an interaction exists between B and Mn; a high B content leads into appearance of signs of Mn deficiency in the plant. For B uptake, N and K must be present in desired amounts. An Fe-B antagonism as well has been reported. Of course, in B deficiency conditions, B uptake increased by adding Fe. Also, an antagonism between B and Fe in the plant has been observed (Salardini, 1994). Kumar et al. (1981) reported that adding Zn to the soil reduced the plant Fe, Mn and Cu and increased plant Zn content. Concurrent Zn and Fe application delayed plant aging and increased the grain carbohydrate content (Hemantaranjan and Gray, 1988). Zinc use, by increasing harvest, reduces the concentration of other elements, including Fe and Mn, due to the dilution effect (Rengel and Graham, 1995). Ming and Yin (1992) reported that the use of each of fertilizers containing Zn and Mn, reduced the concentrations of other elements. Graham et al. (1987) reported that whenever the soil Zn content reduced, the barley plant P, K and Cu content increased while its Fe content was not affected. Parker et al. (1992) showed that Zn application increased plant Mn content but had no effect on its Fe and Cu contents. Mozafar (1987), by studying the effects of 12 nutrients on corn graining, observed that the corn ear Zn, B, Cu, Mn, ca, Mg, N, P, K and sodium contents and unripe ear stem Zn, B, Fe, Cu, Mn, molybdenum, ca and P contents had the same status and showed no significant difference. Studies made on wheat showed that by increase in wheat grain Zn content, the grain K, ca, Mn and Fe decreased, significantly while the grain N, P, Cu, and Zn content increased and Mg content did not change (Ming and Yin, 1992). According to Rengel and Graham (1995) report, by increase in wheat grain Zn content, Fe, Mn, Cu, B, ca, Mg, sodium, K and P contents decreased. Touchton and Boswell (1975), in a study on the effect of B on the corn observed that by B application, the plant B content increased but the Fe, Zn, Mn, Cu, P and K contents did not change.

Considering the numerous applications of corn in human, animal and poultry nutrition and extraction of about 500 different products from it, richness of its grain in Fe and Mn elements plays an effective role in the human health. Also, the grain's being rich in these elements reflects an increase in the grain harvest, qualitatively and quantitatively. Therefore, by studying the effect of Zn-B interaction on the grain, while enriching the grain, we can use its indirect effects to know about its indirect effects, which are the increase in grain harvest, qualitatively and quantitatively. Moreover, it has been established that if grains rich in these elements are used ad seeds, the harvest will increase, qualitatively and quantitatively.

2. Materials and Methods

This research was conducted in the farm of Aref in Abadeh Tashk, Fars province of Iran, during 2009. The area is situated 200 km northeast of the Shiraz, with 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} exchangeable 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}.

For performing the experiment, 20 treatments in 3 replications in the form of completely randomized block design and factorial were considered. The treatments used consisted of 5 levels of Zn (0, 8, 16 and 24 kg ha^{-1} Zn and Zn spray with a 0.5 percent concentration) and 4 B levels (0, 3 and 6 kg ha^{-1} B and spray with a 0.5 percent concentration). Nitrogen, P and K, from sources of urea (46% N), triple super phosphate (46% P_2O_5) and potassium sulfate (50% K_2O) at 180, 70 and 75 kg ha^{-1}, respectively, were added to all treatments. Moreover, 50% of the urea was used when planting and the remainder two times: At vegetative growth and when the corn ears were formed. 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%) Zinc sulfate and 3 per thousand (0.3%) boric acid two times: one at vegetative growth stage and the other after corn ears formation. 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.

Analysis of the grain was carried out using common lab procedures. Phosphorous was measured by Olsen method, available K by acetate ammonium extraction method and K 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 setup. 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 Fe and Mn, and then they were 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. Result and Discussion

Soil test results from soil samples taken in the spring of 2009 are presented in Table 1.

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 Fe content

Different Zn levels showed no significant on the grain Fe content (mg kg^{-1}) (table 2). Application of B to the soil and its spraying had no effect on the grain Fe content relative to no B level but B spraying significantly decreased the grain Fe content relative to B application to the soil (3 and 6 kg ha^{-1} B). The minimum and the maximum grain Fe content, 40.07 and 57.93 mg kg^{-1}, were observed at B spraying and 3 kg ha^{-1} B levels, respectively, but showed no significant difference as compared with the no B level. The Zn-B interaction effect on the grain Fe content was insignificant at 5% level.

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

B (kg ha^{-1})	Zn (kg ha^{-1})					
	0	8	16	24	Foliar Spray	Mean
0	64.47 ab	39.67 bc	46 abc	50 abc	43.67 abc	48.8 ab
3	49.67 abc	66.33 ab	62.33 ab	70.33 a	41 bc	57.93 a
6	46.67 abc	40.67 bc	63.33 ab	52 abc	56.33 abc	51.8 a
Foliar Spray	47.33 abc	41.33 bc	35 c	34.67 a	42 bc	40.07 b
Mean	52.08 a	47 a	51.67 a	51.75 a	45.75 a	

*Means with same letters lack a significant difference at 5% level by Duncan's test

3.2. Iron uptake by the grain

Different Zn levels showed no significant on the Fe uptake by the grain (g ha^{-1}) but the main B effect on Fe uptake was significant at 5% level (table 3). The minimum mean Fe uptake by the grain, 354.77 g ha^{-1}, was at the B spraying level but showed no significant difference relative to the no B level. Application of 3 kg ha^{-1} B significantly increased Fe uptake by the grain, from 378.77 to 517.95 g ha^{-1} (36.74 % increase relative to no B use); but more B use (6 kg ha^{-1} B), showed no significant difference from no B and 3 kg ha^{-1} B levels. Boron spraying significantly reduced Fe uptake by the grain relative to 3 kg ha^{-1} B; but showed no significant difference from the no B level. The maximum Fe uptake by the grain, 517.95 g ha^{-1}, was seen at 3 kg ha^{-1} B level.

The Zn-B interaction effect on Fe uptake by the grain showed that B application left no significant difference from the no B use in any of Zn levels. At high B levels (6 kg ha^{-1} B), only the use of 16 kg ha^{-1} Zn increased Fe uptake by the grain from 335.1 to 617.1 g ha^{-1} (84.15 percent increase relative to no Zn use at that B level). But at other B levels, Zn application had no significant effect on Fe uptake by the grain.

The maximum and the minimum Fe uptake by the grain, 662.1 and 335.1 g ha^{-1}, were seen by application of 24 kg ha^{-1} Zn + 3 kg ha^{-1} B and 6 kg ha^{-1} B, respectively; showing 52.24 % increase and 22.94 % decrease relative to the control, with an uptake of 434.9 g ha^{-1}, respectively. No treatment, including those with the maximum and the minimum Fe uptake by the grain, showed a significant difference from the control.

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

B (kg ha^{-1})	Zn (kg ha^{-1})					
	0	8	16	24	Foliar Spray	Mean
0	439.6 abc	346.6 bc	346.1 bc	394.9 abc	370 bc	378.77 b
3	411.1 abc	589.7 Abc	563.3 abc	662.1 a	363.6 bc	517.95 a
6	335.1 c	352.6 bc	617.1 ab	420.4 abc	513 abc	447.64 ab
Foliar Spray	356.9 bc	352.4 bc	344.3 bc	354.9 bc	365.4 bc	354.77 b
Mean	384.49 a	410.33 a	467.7 a	458.06 a	403.01 a	

*Means with same letters lack a significant difference at 5% level by Duncan's test

3.3. The grain Mn content

Application of Zn at a high level (24 kg ha^{-1} Zn), increased grain Mn content from 3.67 to 4.75 mg kg^{-1} (29.42% increase relative to no B level), but the use of other Zn levels showed no significant effect on the grain Mn content relative to no Zn level (table 4). The maximum and the minimum mean grain Mn content, 3.67 and 4.75 mg kg^{-1}, were seen at no Zn and 24 kg ha^{-1} Zn levels, respectively.

The use of different B levels had no significant effect on the grain Mn content relative to no B level but there was a significant difference between B application to the soil and B spraying; B spraying significantly decreased grain Mn content relative to 3 and 6 kg ha^{-1} B levels. The minimum mean grain Mn content, 3.73 mg kg^{-1}, was seen at B spraying level but showed no significant difference relative to no B level.

The effect of Zn-B interaction on grain Mn content was not significant at 5% level. Joint use of 6 kg ha^{-1} B and 16 kg ha^{-1} Zn made the maximum increase in grain Mn content (6 mg kg^{-1}) showing a 100% increase relative to the control (3 mg kg^{-1}). The minimum grain Mn content, 3 mg kg^{-1}, was seen at no Zn and B use (control). Except for the treatment with the highest grain Mn content, other treatments showed no significant difference from the control.

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

B (kg ha^{-1})	Zn (kg ha^{-1}) 0	8	16	24	Foliar Spray	Mean
0	3 c	5 abc	4.67 abc	4 abc	4.33 abc	4.2 ab
3	4 abc	5.33 abc	3.33 bc	5.57 ab	5.67 ab	4.8 a
6	4 abc	4.33 abc	6 a	4.67 abc	5.33 abc	4.87 a
Foliar Spray	3.67 abc	3.33 bc	3.67 abc	4.67 abc	3.33 bc	3.73 b
Mean	3.67 b	4.5 ab	4.42 ab	4.75 a	4.67 ab	

*Means with same letters lack a significant difference at 5% level by Duncan's test

3.4. Manganese uptake by the grain

Zinc application at all levels significantly increased Mn uptake by the grain (g ha^{-1}) relative to the no Zn level (table 5). The minimum and the maximum Mn uptake by grain, 27.54 and 42.06 g ha^{-1}, were seen at no Zn and 24 kg ha^{-1} Zn levels, respectively. The use of 8, 16, and 24 kg ha^{-1} Zn, significantly increased Mn uptake by the grain from 27.54 at no Zn level to 39.53, 39.64 and 42.06 g ha^{-1}, respectively (43.53, 43.93 and 52.72 % increase in that order); but there was no significant difference at application to the soil levels. Zinc spraying increased Mn uptake by the grain from 27.54 to 40.72 g ha^{-1}, a 47.86 % increase relative to no Zn level, but showed no significant difference from the Zn applied to the soil level. Thus a synergism was seen between Zn application and Mn uptake by the grain.

The main effect of B on Mn uptake by the grain was significant at 5% level. Boron application to the soil increased Mn uptake by the grain relative to no B level but B spraying had no significant effect on Mn uptake. The minimum mean Mn uptake by the grain, 33.48 g ha^{-1}, was seen at no B level. The use of 3 and 6 kg ha^{-1} B, significantly increased Mn uptake by the grain from 33.48 to 42.44 and 41.97 g ha^{-1}, respectively (26.76 and 25.36 % increase relative to no B use, in that order), but there was no significant difference between the two. Boron spraying showed a significant reduction relative to application of B to the soil.

The Zn-B interaction effect on Mn uptake by the grain showed that application of Zn at low levels (0 and 8 kg ha^{-1} Zn) and Zn spraying had no effect on the Mn uptake by the grain but at higher Zn levels (16 and 24 kg ha^{-1} Zn), it increased Mn uptake by the grain. At 16 kg ha^{-1} Zn, only the use of 6 kg ha^{-1} B increased Mn uptake by the grain from 35.1 to 57.8 g ha^{-1} (64.67% increase relative to no B use). The use of 3 kg ha^{-1} B at 24 kg ha^{-1} Zn level, increased Mn uptake by the grain from 29.67 to 52.13 g /ha (75.7 % increase); but other levels of B had no significant effect.

Zinc application at zero and 6 kg ha^{-1} B levels increased Mn uptake by the grain but at other B levels (3 kg ha^{-1} and B spraying) it had no significant effect on Mn uptake. At no B level, only the use of 8 kg ha^{-1} Zn increased Mn uptake by the grain from 20.2 to 44.07 g ha^{-1} (118 % increase). At 6 kg ha^{-1} B as well, only application of 16 kg ha^{-1} Zn increased Mn uptake by the grain from 29.33 to 57.8 g ha^{-1} (97 % increase).

The least Mn uptake by the grain, 20.2 g ha^{-1}, was by no Zn and B use (the control). The highest Mn uptake by the grain, 57.8 g ha^{-1}, was by joint use of 6 kg ha^{-1} B and 16 kg ha^{-1} Zn, a 186 % increase relative to the control.

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

B (kg ha^{-1})	Zn (kg ha^{-1})					
	0	8	16	24	Foliar Spray	Mean
0	202 d	44.07 abc	35.1 bcd	29.67 cd	38.37 abcd	33.48 b
3	32.93 bcd	48.5 abc	30.23 bcd	52.13 ab	48.4 abc	42.44 a
6	29.33 cd	37.23 abcd	57.8 a	38.6 abcd	46.9 abc	41.97 a
Foliar Spray	27.7 cd	28.33 cd	35.43 bcd	47.83 abc	29.2 cd	33.7 b
Mean	27.54 b	39.53 a	39.64 a	42.06 a	40.72 a	

*Means with same letters lack a significant difference at 5% level by Duncan's test

3.5. Correlation between the concentration and total uptake of Fe and Mn in grain with other variables

The correlation coefficients (R) between different variables by the Pearson method and the relevant equations were obtained by the step by step method using the SPSS software. One can use each of the following equations depending on what are the variables measured and R and R^2, but the last equation derived, is the most complete equation containing dependent and independent variables and we must measure more variables to derive that equation. The symbols * and ** in equations and correlation coefficients (R or R^2), are significance at 5% $(\alpha = 0.05)$ and 1% $(\alpha = 0.01)$ levels.

3.5.1. The grain Fe content

The grain Fe content showed a positive correlation with the grain P content (R=0.35), and the Fe uptake by the grain (R=0.89**) and a negative correlation with the leaf K content (R=-0.49*). The equations of which were:

1) FeG = 10.322 + 0.0926 FeUG R = 0.892**

2) FeG = 52.315 + 0.108 FeUG - 0.00568 TGY R^2 = 0.984**

3) FeG = 63.22 + 0.109 FeUG - 0.00598 TGY - 0.0753 FeL R^2 = 0.989**

4) FeG = 69.025 + 0.109 FeUG - 0.00603 TGY - 0.0749 FeL - 0.219 ZnG R^2 = 0.993**

5) FeG = 76.78 + 0.11 FeUG - 0.00597 TGY - 0.0726 FeL - 0.181 ZnG - 0.0284 GTW R^2 = 0.995**

6) FeG = 83.4 + 0.11 FeUG - 0.00572 TGY - 0.0503 FeL - 0.162 ZnG - 0.398 GTW - 0.818 P R^2 = 0.997**

FeG, FeUG, TGY, FeL, ZnG, GTW and P denote grain Fe content (mg kg^{-1}), Fe uptake by the grain (g ha^{-1}), total grain yield (kg ha^{-1}), leaf Fe content (mg kg^{-1}), grain Zn content (mg kg^{-1}), 1000-grain weight (g) and grain protein content (%), respectively.

3.5.2. The grain Mn content

There was a positive correlation between grain Mn content and the grain P content (R=0.35), Zn content (R=0.49*) and B content (R=0.61**); the uptake of N (R=0.38), P (R=0.52*), K (R= 0.41), Fe (R= 0.47*), Mn (R= 0.94**), Zn (R= 0.71**) and B (R= 0.66**) by the grain; total grain yield (R= 0.46*), the number of grains in the ear length (R= 0.4) and the number of grains across the ear diameter (R=0.45*), and a negative correlation with leaf B content (R= -0.3) and the percentage of grain in the ear (R= -0.37). The relevant equations were:

1) MnG = 1.192 + 0.0846 MnUG R = 0.943**

2) MnG = 3.993 + 0.113 MnUG - 0.000454 TGY R^2 = 0.985**

MnG, MnUG and TGY are grain Mn content (mg kg^{-1}), Mn uptake by the grain (g ha^{-1}) and total grain yield (kg ha^{-1}), respectively.

3.5.3. The Fe uptake by the grain

The Fe uptake by the grain showed a positive correlation with the grain P content (R= 0.48*), Fe content (R= 0.89**), Mn content (R= 0.47*) and B content (R= 0.45*); the uptake of N (R=0.31), P (R=0.49*), Mn (R=0.52*), Zn (R=0.35) and B (R=0.49*) by the grain; and total grain yield (R= 0.33) and a negative correlation with leaf K content (R=-0.43). The equations were:

1) FeUG = -2.221 + 8.599 FeG R = 0.892**

2) FeUG = - 474.065 + 9.09 FeG + 0.0523 TGY R^2 = 0.985**

3) FeUG = -575.283 + 9.103 FeG + 0.0549 TGY + 0.691 FeL R^2 = 0.99**

4) FeUG = -626.702 + 9.071 FeG + 0.055 TGY + 0.683 FeL + 2.017 ZnG R^2 = 0.994**

5) FeUG = - 697.792 + 9.081 FeG + 0.0544 TGY + 0.661 FeL+ 1.656 ZnG + 0.258 GTW R^2 =0.996**

6) FeUG = - 758.18 + 9.084 FeG + 0.0521 TGY + 0.458 FeL + 1.48 ZnG + 0.362 GTW + 7.45 P R^2 = 0.997**

FeUG, FeG, TGY, FeL, ZnG, GTW and P are Fe uptake by the grain (g ha^{-1}), grain Fe content (mg kg^{-1}), total grain yield (kg ha^{-1}), leaf Fe content (mg kg^{-1}), grain Zn content (mg kg^{-1}), 1000-grain weight and grain protein content (%), respectively.

3.5.4. The Mn uptake by the grain

There was a positive correlation between Mn uptake by the grain and the leaf Zn content (R= 0.31); grain P content (R= 0.43), Mn content (R= 0.94^{**}), Zn content (R= 0.35) and B content (R= 0.66^{**}); the uptake of N (R= 0.63^{**}), P (R= 0.73^{**}), K (R= 0.61^{**}), Fe (R= 0.52^{*}), Zn (R= 0.76^{**}), Cu (R= 0.41) and B (R= 0.8**) by the grain; ear weight (R= 0.48), grain weigh in the ear (R= 0.42), total grain yield (R= 0.71^{**}), the number of grains in the ear length (R=0.57^{**}), the number of grains across the ear diameter (R= 0.51^{*}). The relevant equations were:

1) MnUG = -8.293 + 10.498 MnG $R = 0.943^{**}$

2) MnUG = -35.219 + 8.673 MnG + 0.00409 TGY $R^2 = 0.991^{**}$

3) MnUG = -32.572 + 8.279 MnG + 0.00357 TGY + 0.0427 BUG $R^2 = 0.991^{**}$

MnUG, MnG, TGY and BUG are Mn uptake by the grain (g ha^{-1}), grain Mn content (mg kg^{-1}), total grain yield (kg ha^{-1}) and B uptake by the grain (g ha^{-1})

4. Conclusion

The effects of Zn, B (relative to no B level) and the effect of Zn-B interaction on the grain Fe content were insignificant. Zinc application had no effect on Fe uptake by the grain and among different B levels, only application of 3 kg ha^{-1} B significantly increased Fe uptake by the grain. The B effect on Fe uptake by the grain did not depend on the soil Zn content. Also, Zn application only at high B levels (6 kg ha^{-1} B) increased Fe uptake by the grain but had no effect at other levels. The B effect (relative to no B level) and the effect of Zn-B interaction on grain Mn content was not significant and among different Zn levels, only application of 24 kg /ha Zn increased grain Mn content. The main Zn, B and Zn-B interaction effects on Mn uptake by the grain, was significant. Zinc application at all levels increased Mn uptake by the grain. The minimum and the maximum Mn uptake by the grain were seen at no Zn and 24 kg ha^{-1} Zn levels, respectively. Boron application to the soil increased Mn uptake by the grain but B spraying had no effect on it. The minimum mean Mn uptake by the grain, 33.48 g ha^{-1}, was seen at no B level. Therefore, there was a synergism between Zn and Mn as well as B and Mn. Boron use at high Zn levels (16 and 20 kg ha^{-1} Zn) increased Mn uptake by the grain, but at other Zn levels, no effect was seen. Therefore, a high Zn level helped with B affecting the increase in Mn uptake by the grain. Application of Zn at 0 and 6 kg ha^{-1} B levels increased Mn uptake by the grain but had no effect at other B levels.

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