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Combined effect of Zinc and Boron on yield and nutrients accumulation in corn

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Abstract

The event of partly grain-free ear is a crucial problem which can result in severe reductions in corn yield. In a two year field investigation, during 2003-2004, an experiment was conducted to determine the effect of boron (B) and zinc (Zn) application on yield and yield components of corn (*Zea mays* L.) plants grown in a B and Zn-deficient calcareous soil (fine, carbonatic, thermic, Typic Haploxerepts) of southern Iran. Treatments consisted of five levels of Zn (soil application of zinc sulfate at the rates of 0, 8, 16 and 24 kg ha^{-1} and foliar spray of Zn solutions containing 0.3 weight percent of zinc sulfate) and four levels of B (soil application of boric acid at the rates of 0, 3 and 6 kg ha^{-1} and foliar spray of B solutions containing 0.1 weight percent of boric acid). Zn and B solutions were applied at the rate of 1000 L ha^{-1}. Zn and B fertilization significantly increased plant biological yield, grain yield, thousand grain weight, number of grains per stalk, grain protein content and the concentration of B and Zn in corn tissues. There was a significant B × Zn interaction on corn yield and tissue nutrient concentrations. In general, the effect of B × Zn interaction was synergistic on corn growth and yield. Although B and Zn fertilization made significant changes in some plant nutrients, the changes were slight enough not to affect plant growth and production. It was concluded that the event of partly grain- free ear in corn is proportionally related to B and Zn deficiency in calcareous soils of southern Iran. It can be recommended that in calcareous soils of southern Iran with low levels of available Zn and B, soil application of 16- 24 kg ha^{-1} of zinc sulfate and foliar application of B solution containing 0.1 weight percent of boric acid (1000 L ha^{-1}) may be applied for enhancement of grain yield and reduction of partly grain-free ear in corn. Further, it is recommended that more attention should be paid to Zn and B nutrition of corn plants in calcareous soils having low availability of these tow nutrients.

Keywords: Zinc; Boron; Corn; Grain production; Seed Set.

Introduction

Corn is a strategic crop in Iran agriculture; therefore increase in its yield and production has received a great attention in recent years. The event of partly grain- free ear is a crucial problem which can result in severe reductions in corn yield. While some researchers believe that, water and heat stresses during the pollination process are the main causes of the event, others notify that nutritional disorders are noticeably involved in the incidence of this difficulty. Among micronutrients, boron (B) and zinc (Zn) play a key role in pollination and seed set processes; so that their deficiency can cause decrease in seed formation and subsequent yield reduction. Vitosh et al., (1997) expressed that B is involved in carbohydrates metabolism and it is essentially necessary for protein synthesis, pollen germination and seed and cell wall formation. Rehem et al (1998) stated that B plays a key role in water and nutrients transportation from root to shoot. They believe that boron shortage causes barren stalks and small, twisted ears. Since many factors can cause small, twisted ears of corn; they suggest having both soil and corn plant samples analyzed for boron before confirming a deficiency. Sometimes water stress and B deficiency are in companion with each other. For example B deficiency is intensified by water stress. According to a review reported by Marschner (1995), B is relatively immobile in plant tissues and its transportation is further hindered under water stress circumstances. Similarly Zn supply is considered as an important factor in reproduction process. According to Brown et al (1993) formation of male and female reproductive organs and pollination process are disturbed in Zn deficiency which may be attributed to the reduction of Indol acetic acid (IAA) synthesis. Marschner (1995) declared that following Zn deficiency, reduction in RNA-polymerase activity and increase in RNA destruction can severely reduce the seed protein content. Studies have revealed that, B and Zn are interestingly related with each other. Graham et al., (1987) reported that low Zn treatment did not affect plant growth, but enhanced B concentration to a toxic level in barley (*Hordeum vulgare*). Similarly, Zn deficiency enhanced B concentration in wheat plants (*Triticum aestivum*) grown on Zn deficient soils (Singh et al., 1990). Sinha et al., (2000) noted a synergistic interaction between Zn and B in mustard (*Brassica nigra*) when both the nutrients were either in low or excess supply. Hosseini et al., (2007) reported that there was a significant B and Zn interaction on corn growth and tissue nutrient concentration which were rate dependent. In general, the effect was antagonistic in nature on nutrient concentration and synergistic on plant growth.

In southern Iran, Zn deficiency is a nutritional disorder in many plants grown on calcareous soils with pH>8.0. Similarly, soil pH is an important factor that affects B uptake by plants. Many investigators (Bartlett and Picarellin, 1973; Peterson and Newman, 1976; Gupta and Macleod, 1981) have found that increasing soil pH by liming to above pH 6.5 reduces B concentration in many plants. Since these two nutrients are significantly involved in reproduction process and their deficiency may occur simultaneously in calcareous soils of Iran; this field experiment was carried out to investigate the effect of B and Zn application on grain yield production and seed set of corn.

Materials and Methods

Experimental site

The experimental site is located in Experimental Station of Fars Research Center for Agriculture and Natural Resources, Zarghan, Iran, which is under cultivation of agronomic crops. The area is located at 29^o 35$'$ N, 52^o 35$'$ E, and 1810 m above mean sea level. Its climate is semi-arid with warm summers. Mean annual precipitation is 415 mm and maximum and minimum mean monthly air temperature are 22.5 and 2.5 ^oC, respectively. Soil of the region is calcareous (fine, carbonatic, thermic, Typic Haploxerepts) with low salinity and organic matter. Each year, soil samples were collected from surface horizon (0-30 cm) of the soil, air-dried, passed through a 2-mm sieve and analyzed for the following properties. Particle-size distribution determined by hydrometer method (Gee and Bauder, 1986), soil pH and EC_e were measured in saturated paste and saturated extract, respectively, total neutralizing value (TNV) was determined by neutralization with HCl (Loeppert and Suarez, 1996), cation exchange capacity (CEC) and organic compound (OC) (OM) were determined by replacing cations with NaOAc (Summer and Miller, 1996) and Walkley-Black method (Nelson and Sommers, 1996), respectively. Available Zn, Fe, Mn, and Cu were determined by DTPA extraction (Lindsay and Norvell, 1978) and phosphorus by sodium bicarbonate extraction (Olsen et al., 1954). Soil available B was extracted by hot water (Berger and Truog, 1939) and measured by azomethine-H colorimetric method (Bingham, 1982). The characteristics of the soil materials are presented in Table 1.

Table 1. Some soil physical and chemical properties of selected field.

Years	EC_e dS m^{-1}	pH	TNV	OC	P	K	Fe	Mn	Cu	Zn	B
			(%)		(mg kg^{-1})						
First year	1.95	8.1	34.0	0.49	8.4	188	5.6	10.6	1.21	0.71	0.56
Second year	2.67	8.2	31.0	0.55	14.6	173	3.8	8.7	0.57	0.44	0.61

Field experiment

A two year field experiment was conducted during 2003-2004 in the calcareous soil to investigate the effect of B and Zn application on biological yield, grain yield, yield components and tissue nutrient concentration of corn. The experiment was factorial in a Randomized Complete Block Design, composed of 20 treatments and three replicates. Treatments consisted of five levels of Zn (soil application of zinc sulfate at the rates of 0, 8, 16 and 24 kg ha^{-1} and foliar application of Zn solution containing 0.3 weight percent of zinc sulfate) and four levels of B (soil application of boric acid at the rates of 0, 3 and 6 kg ha^{-1} and foliar application of B solution containing 0.1 weight percent of boric acid). Soil treatments were applied at the time of corn plantation, while foliar solutions were sprayed at the rate of 1000 L ha^{-1} when corn plants were in 6-7 leaf stage. The basal fertilizer applications were 80 kg ha^{-1} of nitrogen (N) as urea, 50 kg ha^{-1} of phosphorus (P) as triple super phosphate, 60 g ha^{-1} of iron (Fe) as iron ethylenediamine di-hydroxyphenyl acetic acid (Fe- EDDHA). Every year corn seeds were planted in 25 m^2 plots on July. Each plot consisted of four, 8.3 m long rows of corn with row and plant distance of 75 and 20 cm, respectively. Sowing was done by an experimental seeder with the seeding rates of 25 kg ha^{-1} (cv. 704), and seedlings were thinned 2 weeks after emergence. The rest of N (100 kg ha^{-1} of N as urea) was top-dressed in two equal splits during 6-7 and 10-12 leaf stages. Every year plants were harvested on November and biological yield, grain yield and yield components including grain yield, thousand grain weight, and number of grains per stalk were determined for each plot.

Plant analytical procedure

Leaf and grain samples were collected at 70 days after emergence and harvest time, respectively. All samples rinsed with distilled water, dried at 70 ^{o}C for 48 h in an oven and ground to pass a 40-mesh sieve. The ground plant samples were dry- ashed at 500 ^{o}C, dissolved in 2 N of hydrochloric acid (HCl) and made to 100 ml volume with hot distilled water. In leaf extracts B determination was made by the azomethine-H colorimetric method (Bingham, 1982), Zn by atomic absorption spectrophotometer, total N by micro-Kjeldhal method, P by spectrophotometer and K by flame photometer. In grain extracts only the concentration of B and Zn was measured by the above mentioned methods.

Statistical analysis

The data were subjected to statistical analysis using MSTATC computer software. The Least Significant Difference Test (LSD) was also performed to identify the homogenous sets of data.

Results and Discussion

Physiochemical characteristics of the soil and water

The characteristics of the soil materials are presented in Table 1. Results show that the soil materials had no salinity problem, and contained low organic matter, medium to high TNV, medium concentration of potassium (K), manganese (Mn), iron (Fe) and copper (Cu), and low concentration of phosphorous (P), Zn and B. Water used for corn irrigation had suitable quality with low B concentration (Table 2).

Table 2. Chemical properties of irrigation water.

Years	EC_e dS m^{-1}	pH	HCO_3^-	Cl^-	HBO_3^-	SO_4^-	Total anions	Mg^{++}	Ca^{++}	Na^+	Total cations	SAR
							(meq l^{-1})					
First year	0.42	7.9	2.4	0.7	nd*	1.2	4.3	0.5	3.5	0.5	4.5	0.35
Second year	0.94	8.1	3.2	2.4	0.2	4.0	10.6	2.5	0.8	6.5	9.8	3.88

* nd: not determined

Biological yield and grain yield

F values and level of significance from ANOVA on biological yield, grain yield, yield components and grain protein content are shown in Table 3. Biological and grain yields were significantly affected by single (P<0.01) and simultaneous (P<0.05) application of B and Zn. Enhancement in the level Zn and B application, significantly increased the biological and grain yield of corn as compared to control. For example enhancement in soil application of Zn from zero to 24 kg ha^{-1} and foliar Zn application as compared to control increased corn biological yield by 43 and 15.6% and con grain yield by 20 and 30% respectively (Table 4). The corresponding figures for soil application and foliar spray of B were 16.8 and 16.6% in regard to biological yield or 9 and 21.4% for grain yield (Table 4). The highest biological and grain yield were produced by plants that received soil application of 24 kg Zn ha^{-1} and foliar spray of B. According to Brown et al., (1993) formation of male and female reproductive organs and pollination process are disturbed in Zn deficiency, which in result causes a sever reduction in plant yield. They attribute this event to the reduction of Indol acetic acid (IAA) synthesis. Rehem et al., (1998) stated that B plays a key role in water and nutrients transportation from root to shoot. They believe that boron shortage can cause barren stalks and small, twisted ears. Vitosh et al., (1997) reported that B is essentially necessary for pollen germination and growth of pollen tube. They believe that B uptake is negligible in calcareous soils with high pH, so that disturbance in pollination process and abortive plants are the common features of such circumstances.

Table 3. Analysis of variance for biological yield, yield components and grain protein content.

Sources of deviation	df	Biological yield	Grain yield	Thousand grain weight	Grains per stalk	Protein content
Replication	2	4.08^{*}	9.1^{**}	21.1^{**}	17.3^{**}	1.84^{ns}
Zn levels	4	6.63^{**}	10.4^{**}	9.9^{**}	11.4^{**}	7.46^{**}
B levels	3	5.03^{**}	6.2^{**}	2.0^{ns}	4.7^{**}	6.13^{**}
Zn*B	12	2.20^{*}	2.2^{*}	6.0^{**}	2.2^{*}	3.88^{**}
Year	1	0.001^{ns}	0.34^{ns}	0.06^{ns}	0.002^{ns}	0.001^{ns}
Zn * year	4	0.001^{ns}	0.04^{ns}	0.03^{ns}	0.001^{ns}	0.001^{ns}
B* year	3	0.001^{ns}	0.06^{ns}	0.04^{ns}	0.001^{ns}	0.001^{ns}
Zn* B* year	12	0.001^{ns}	0.17^{ns}	0.02^{ns}	0.002^{ns}	0.001^{ns}
CV		15.6	11.2	5.6	8.7	7.2

**: P<0.01; *: P<0.05; ns: non significant

Yield components

While single Zn and B application had significant (P<0.01) effects on total grain number per stalk, thousand grain weight was only affected (P<0.01) by Zn application (Table 3). Zn and B treatments made significant increases in the number of total grains per stalk (Table 5). For example enhancement in soil application of Zn from zero to 24 kg ha^{-1} and foliar Zn application as compared to control increased the number of total grains per stalk by 16.9 and 14% respectively. The corresponding figures for soil application and foliar spray of B were 9.6 and 13.8% respectively. These results were in agreement with those reported by Brown et al., (1993), Cakmak et al., (1996), Grewal et al (1998) and Hosseini et al., (2007). Zn application increased thousand grain weight in corn plants. Yilmaz et al., (1997) reported that following Zn fertilization, thousand grain weight showed an increase of %26 in wheat plants. Hemantaranjan and Grag (1988) observed that optimum utilization of Zn and Fe significantly increased thousand grain weight in wheat. They declared that, total content of carbohydrates, starch, IAA, chlorophyll and seed protein were significantly increased by consumption of these two nutrients. They believe that more production of chlorophyll and IAA can cause delay in plant oldness and prolong the period of photosynthesis. This incident improves the production of carbohydrates and their transportation to the growing seeds. B and Zn rates, and their interaction had significant effects ($P<0.01$) on grain protein content (Table 3). These two nutrients significantly increased grain protein content of corn plants. On average, increases in grain protein content by single B and Zn fertilization were 8% and 10%, respectively. Highest grain protein content (11.3%) was obtained when these two nutrients were applied by foliar spray. Marschner (1995) declared that Zn is essentially necessary for protein synthesis and following Zn deficiency, reduction in RNA-polymerase activity and increase in RNA destruction can severely reduce grain protein content.

Table 4. Effect of B and Zn application on biological yield and grain yield.

Applied B kg ha^{-1}	Applied Zn in soil (kg ha^{-1}) 0	8	16	24	Foliar Zn (0.3 %)	Mean
			Biological yield (kg ha^{-1})			
0	11361	11972	12917	16278	13139	13133
3	12167	15194	14389	16167	14917	14566
6	13278	17222	15889	13583	14972	14989
Foliar B (0.1 %)	13250	13946	16778	16472	15139	15117
Mean	12514	14583	14993	15625	14542	
			Grain yield (kg ha^{-1})			
0	6775	8650	7617	8150	8808	8000
3	8275	9033	9025	8158	8717	8842
6	7383	8667	8708	8192	9033	8597
Foliar B (0.1 %)	8225	8650	9808	10083	7817	8997
Mean	7490	8750	9040	8896	8869	
LSD 5%		Biological yield			Grain yield	
Zn		1002			554	
B		896			495	
Zn*B		2004			1107	

B and Zn concentration in corn leaf and grain

F values and level of significance from ANOVA on concentration of plant nutrients in corn plant are shown in Table 6. Also, Zn and B concentrations in plant leaf as affected by B and Zn application are shown in Table 7. Although increasing additions of Zn to soil or foliar spray of this element significantly increased the concentration of Zn in corn leaf as compared to control, the effect of Zn foliar spray on the enhancement of Zn concentration was more pronounced than soil application (Table 7). In contrast to Zn, B fertilization decreased the concentration of Zn in corn leaf. Almost a similar trend was observed in the case of B concentration in plant leaf; so that B fertilization enhanced the concentration of B in plant leaves, but Zn fertilization decreased it significantly. The effect of B and Zn application on concentrations of Zn and B in corn grain is shown in Table 8. Mean concentration of Zn in corn grain was enhanced by soil application or foliar spray of Zn but decreased with B fertilization (Table 8). On the other hand, when mean grain concentration of B was increased with B addition, soil Zn fertilization had not definite effect on this plant response. Studies have revealed that, B and Zn are interestingly related with each other. Graham et al., (1987) reported that low Zn treatment did not affect plant growth, but enhanced B concentration to a toxic level in barley (*Hordeum vulgare*). Similarly, Zn deficiency enhanced B concentration in wheat (*Triticum aestivum*) grown on Zn deficient soils (Singh et al, 1990). Sinha et al., (2000) noted a synergistic interaction between Zn and B in mustard (*Brassica nigra*) when both nutrients were either in low or excess supply. Hosseini et al., (2007) reported that there was a significant B and Zn interaction on corn growth and tissue nutrient concentration which were rate dependent. They declare that in general, the effect was antagonistic in nature on nutrient concentration and synergistic on plant growth.

Table 5. Effect of B and Zn application on thousand grain weight, number of grains per stalk and grain protein content.

Applied B kg ha^{-1}	Applied Zn in soil (kg ha^{-1}) 0	8	16	24	Foliar Zn (0.3 %)	Mean
			Thousand grain weight (g)			
0	329	359	334	374	314	336
3	330	336	349	355	324	334
6	345	355	343	344	340	343
Foliar B (0.1 %)	365	362	334	326	333	343
Mean	327	353	340	350	328	
			Number of grains per stalk			
0	479	584	553	560	546	544
3	510	582	596	586	599	575
6	525	638	617	584	574	588
Foliar B (0.1 %)	545	561	587	627	553	584
Mean	515	591	588	601	569	
			Grain protein content (%)			
0	8.5	9.1	9.6	8.6	9.9	9.2
3	9.5	9.3	9.4	10.2	9.5	9.6
6	9.9	9.4	10.3	9.6	9.7	9.8
Foliar B (0.1 %)	9.8	9.5	10.0	9.7	11.3	9.9
Mean	9.2	9.3	9.9	9.5	10.1	
LSD 5%	Thousand grain weight		Grains per stalk		Grain protein	
Zn	10.9		27.6		0.34	
B	9.7		27.7		0.31	
Zn*B	21.8		55.2		0.68	

Table 6. Analysis of variance for nutrient concentration in plant leaf and grain.

Sources of deviation	df	Shoot N	P	K	Zn	B	Grain Zn	B
Replication	2	4.78**	8.02**	10.04**	3.9^{ns}	9.53**	2.27^{ns}	0.36^{ns}
Zn levels	4	7.98**	10.05**	1.54^{ns}	16.3**	10.6**	3.40**	2.90*
B levels	3	9.78**	22.24**	6.14**	11.2**	6.8**	3.13*	7.54**
Zn*B	12	2.44**	2.85**	7.36**	3.6^{ns}	9.9**	1.7^{ns}	1.89*
Year	1	-	–	–	–	–	0.02^{ns}	0.03^{ns}
Zn * year	4	–	–	–	–	–	0.18^{ns}	0.13^{ns}
B* year	3	–	–	–	–	–	0.20^{ns}	0.28^{ns}
Zn* B* year	12	-	-	-	-	-	0.20^{ns}	0.26^{ns}
CV		4.0	5.2	5.0	20.1	19.2	16.4	14.0

**: P<0.01; *: P<0.05; ns: non significant

Table 7. Effect of B and Zn application on concentration of Zn and B in corn leaf.

Applied B kg ha^{-1}	Applied Zn in soil (kg ha^{-1}) 0	8	16	24	Foliar Zn (0.3 %)	Mean
			Zn concentration (μg g^{-1})			
0	27.0	48.7	38.0	40.0	58.3	42.4
3	39.7	35.7	40.0	51.0	52.0	43.7
6	31.0	32.0	36.3	34.7	40.0	32.8
Foliar B (0.1 %)	35.0	32.7	40.7	30.3	52.3	39.6
Mean	33.2	37.3	38.8	38.3	50.7	
			B concentration (μg g^{-1})			
0	42.4	33.3	34.0	30.5	37.7	36.9
3	60.2	50.8	36.7	39.9	31.9	43.9
6	65.0	30.6	32.3	49.2	42.6	43.9
Foliar B (0.1 %)	35.6	57.0	39.0	46.7	52.9	46.2
Mean	50.0	42.9	35.5	41.6	41.3	
LSD 5%		Zn concentration			B concentration	
Zn		3.86			3.22	
B		3.45			2.88	
Zn*B		7.70			6.44	

Table 8. Effect of B and Zn application on concentration of Zn and B in corn grain.

Applied B kg ha^{-1}	Applied Zn in soil (kg ha^{-1}) 0	8	16	24	Foliar Zn (0.3 %)	Mean
			Zn concentration (μg g^{-1})			
0	21.3	29.8	33.0	26.50	28.2	28.0
3	24.3	27.7	25.0	25.46	26.3	26.3
6	23.7	26.0	27.2	27.01	27.0	25.9
Foliar B (0.1 %)	24.5	24.5	23.8	25.88	27.7	24.6
Mean	23.5	27.0	27.3	26.0	27.3	
			B concentration (μg g^{-1})			
0	8.37	8.81	9.25	6.50	7.57	8.10
3	8.60	9.08	8.47	8.46	10.63	9.05
6	9.00	10.07	9.92	9.35	9.73	9.61
Foliar B (0.1 %)	9.40	9.20	8.92	8.88	9.77	9.23
Mean	8.84	9.29	9.14	8.30	9.43	
LSD 5%		Zn concentration			B concentration	
Zn		2.35			0.62	
B		2.10			0.55	
Zn*B		4.70			1.24	

N, P and K concentration in corn leaf

Zn and B fertilization had slight but significant effects on leaf concentration of selected macronutrients (Tables 6 and 9). Increments in B addition by both methods of fertilizer application significantly decreased the concentration of N and P in corn leaf (Table 9). Since biological yield of corn plants showed a significant increase with B addition; reduction in leaf concentration of N and P can be attributed to a dilution effect. K concentration in corn leaf did not follow a definite trend with B addition. While Zn treatments had no significant effect on leaf concentration of K, mean leaf concentration of N and P showed slight but significant increases with Zn fertilization (Table 9). Judging from these data it can be concluded that the influence of Zn and B fertilization on the enhancement of corn growth and production is due to the sole function of these nutrients rather than to their effects on selected macronutrients concentration.

Table 9. Effect of B and Zn application on N, P and K concentration in corn leaf.

Applied B kg ha^{-1}	Applied Zn in soil (kg ha^{-1}) 0	8	16	24	Foliar Zn (0.3 %)	Mean
			N concentration (%)			
0	3.50	3.49	3.36	3.56	3.51	3.48
3	3.22	3.38	3.48	3.38	3.48	3.39
6	3.10	3.41	3.21	3.39	3.36	3.29
Foliar B (0.1 %)	3.20	3.40	3.47	3.48	3.38	3.38
Mean	3.26	3.42	3.38	3.45	3.43	
			P concentration (%)			
0	0.223	0.257	0.240	0.233	0.237	0.238
3	0.217	0.223	0.230	0.227	0.220	0.223
6	0.197	0.220	0.220	0.207	0.230	0.215
Foliar B (0.1 %)	0.210	0.220	0.230	0.227	0.213	0.220
Mean	0.210	0.230	0.230	0.223	0.225	
			K concentration (%)			
0	3.19	3.58	3.44	3.18	3.46	3.37
3	3.33	3.10	3.40	3.28	3.31	3.28
6	3.86	3.41	3.35	3.38	3.35	3.47
Foliar B (0.1 %)	3.28	3.23	3.51	3.53	3.39	3.39
Mean	3.42	3.33	3.13	3.34	3.38	

LSD 5%	N concentration	P concentration	B concentration
Zn	0.07	0.0005	0.26
B	0.06	0.0004	0.23
Zn*B	0.14	0.0001	0.51

Conclusions

Because of the calcareous nature of soils in southern Iran, associated with high levels of soil pH, most micronutrients have negligible availability in these soils. This condition may lead to some nutritional disorders that go along with the deficiency of such micronutrients. The results of this study showed that the event of partly grain-free ear in corn is proportionally related to the low bioavailability of Zn and B in such soils. The observation that the disorder can be alleviated by Zn and B application has a potential and practical importance as B and Zn deficiency are simultaneously encountered in some soils of arid and semiarid regions. According to two years of field experiment, it can be recommended that in calcareous soils of southern Iran with low levels of available Zn and B, soil application of 16- 24 kg ha^{-1} of zinc sulfate and foliar application of B solution containing 0.1 weight percent of boric acid (1000 L ha^{-1}) may be applied for enhancement of grain yield and reduction of partly grain-free ear in corn. However, it needs a great attention that fertilizer recommendation is greatly related to soil and climatic conditions and it is not feasible to recommend a single application formula for different situations. Finally, it is recommended that more attention should be paid to Zn and B nutrition of corn plants in calcareous soils having low availability of these nutrients.

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References

Bartlett, R.J., Picarellin C.J., 1973. Availability of boron and phosphorous as affected by liming in acid potato soil. Soil Sci. 116, 77-83.

Berger, K.C., Truog, E., 1939. Boron determination in soils and plants. Indu. Eng. Chem. J. 11, 540-545.

Bingham, F.T., 1982. Boron. In: Page, A.L. (Ed.), Methods of Soil Analysis. Part 2, Am. Soc. Agron. Madison, WI. pp. 431-448.

Brown, P. H., Cakmak, I. Zhang, Q., 1993. Form and function of zinc in plants. PP.93-1.6. In: A. D. Robson (ed). Zinc in Soil and Plants. Kluwar Academic Publishers. Dordecht, The Netherlands.

Cakmak, I., Yilmaz, A., Kalayli, Ekiz, E., Torun, B., Ernoglu, B., Brown, H. J., 1996. Zinc deficiency as a critical problem in wheat production in central Anatolia. Plant and Soil. 180, 165-172.

Gee, G. W., Bauder, J. W., 1986. Particle-size analysis, hydrometer method. In: Klute, A. (Ed.), Methods of Soil Analysis, Part I, 3rd Ed., Am. Soc. Agron., Madison. WI. pp. 404-408.

Graham, R.D., Welch, R.M., Grunes, D.L., Cary, E.E., Norvell, W.A., 1987. Effect of zinc deficiency on the accumulation of boron and other mineral nutrients in barely. Soil Sci. Soc. Am. J. 51, 652-657.

Grewal, H.S., Graham, R.D., Stangoulis, J., 1998. Zinc-boron interaction effects in oilseed rape. J. Plant Nutr. 21(10), 2231-2243.

Gupta, U.C., Macleod, J.A., 1981. Plant and soil boron as influenced by soil pH and calcium sources on podzol soils. Soil Sci. 131(1), 20-25.

Hemantaranjan, A., Grag, O. K., 1988. Iron and zinc fertilization with reference to the grain quality of *triticum Aestiuvm* L. J. Plant Nutr. 11(6-11), 1439-1450.

Hosseini, S.M., Maftoun, M., Karimian, N., Rounaghi, A., Emam, Y., 2007. Effect of zinc × boron interaction on plant growth and tissue nutrient concentration of corn. J. Plant Nutr. 30, 773-781.

Lindsay, W.L., Norvell, W.A., 1978. Development of a DTPA test for zinc, iron, manganese, and copper. Soil Sci. Soc. Am. J. 42, 421-428.

Loeppert, R. H., Suarez, D. L., 1996. Carbonate and gypsum. In: Sparks, D. L. (ed.), Methods of Soil Analysis. Part III. 3rd Ed. Am. Soc. Agron., Madison,WI. pp. 437-474.

Marschner, H., 1995. Mineral nutrition of higher plants. 2 rd Ed. Academic Press.

Nelson, D. W., Sommers, L. E., 1996. Total carbon, organic carbon, and organic matter. In: Sparks, D. L. (ed.), Methods of Soil Analysis. Part III, 3rd Ed. Am. Soc. Agron., Madison,WI. pp. 961-1010.

Olsen, S. R., Cole, C. V., Watanabe, F. S., Dean, L. A., 1954. Estimation of available phosphorus in soil by extraction with sodium bicarbonate. USDA. Circ. 939. U. S. Gov. Print. Office, Washington, D.C.

Peterson, L.A., Newman, R. 1976. Influence of soil pH on the availability of added boron. Soil Sci. Soc. Am. J. 40, 280-282.

Rehem, G. W., Fendter, W. E., and Overdahi, C. J., 1998. Boron for Minnesota soils. University of Minnesota Extension Service [Online]. Available at http://www.Extansion Umn. Edv.

Singh, J.P., Dahiya, D.J., Norwal, R.P., 1990. Boron uptake and toxicity in wheat in relation to zinc supply. Fert. Res. 24, 105-110.

Sinha, P., Jain, R., Chatterjee, C., 2000. Interactive effect of boron and zinc on growth and metabolism of mustard. Commun. Soil Sci. Plant Anal. 31(1, 2), 41-49.

Summer, M. E., Miller, W.P., 1996. Cation exchange capacity and exchangeable coefficients. In: Sparks, D. L. (ed.) Method of Soil Analysis. Part III. 3rd Ed. Am. Soc. Agron., Madison,WI. pp. 1201-1229.

Vitosh, M. L., Warneke D. D., and Lucas R. E.,1997. Boron. Mishigan State University Extention Soil and Manegemnt Fertilizer. Available on the htpp://www.Msue.msu.EDV.

Yilmaz, A., Ekiz, H., Torun, B., Gulekin, I., Karanlink, S., Bagci, S. A., Cakmak., I. 1997. Effect of different zinc application methods on grain yield and zinc concentration in wheat cultivars grown on zinc-deficient calcareous soils. J. Plant Nutr. 20(4-5), 461-471.