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EFFECT OF DIFFERENT ZINC AND BORON APPLICATION METHODS ON LEAF NITROGEN, PHOSPHORUS AND POTASSIUM CONCENTRATIONS IN MAIZE GROWN ON ZINC AND BORON DEFICIENT CALCAREOUS SOILS

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ABSTRACT

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Analysis of nutrient concentrations in plant tissue at certain critical growth stages has often been used as an effective tool to diagnose nutrient disorder problems in field crop production. Two studies on the response of maize (*Zea mays* L.) to Zn and B applications were carried out on soils in the region of the Fars province of Iran during 2009-2010 growing seasons. Results revealed that the mean N and K concentrations in the leaf were below the critical level but P concentration was sufficient for corn. There was a synergism between Zn-P and between B-K and an antagonism between B-P. The presence of a high amount of B in the soil assisted to increasing of leaf P content by Zn application. With increasing of Zn content, the higher rate of B was needed for increasing K concentration in the leaf by B application.

Key words: *fertilizer, critical level, interaction, available, synergism, antagonism*

INTRODUCTION

Plant analysis is one of the accepted tools for diagnosing deficiency disorders. Deficient plants, if analysed at the right stage, usually contain lower amount of the deficient element than the corresponding healthy checks (Katyal and Sharma, 1980). For this reason leaf tissue analysis has been widely used for nutrient evaluation of a large range of crop species. Leaf analyses are particularly useful for monitoring long-term fertility management in perennial crops such as pecans (Walworth *et al.* 2005). An interpretation of a plant analysis is based on comparing the elemental concentration found against a sufficiency range. The concentration of each element analyzed is reported as less than, greater than or within the sufficiency range. If soil test data and cultural practice information are supplied, an explanation for element concentrations outside the sufficiency range is given (Hodges 2010). An alternative to soil testing is to analyse samples of leaves or grain to determine the nutrient status of both crop and soil on which it is growing. However, it is not often possible to rectify the problem to prevent the losses in the existing crop, but once diagnosed, the deficiency can be treated for future crops in time to prevent further losses of yield. Leaf sampling practices vary with regard to which leaves are sampled and this is the result of local experience (Imtiaz *et al.* 2010). The transition zone between deficient and adequate is the critical nutrient concentration and is generally defined as that concentration where the growth or yield is 10% less than the maximum. This concentration is dependent upon plant growth stage, plant part and its physiological age, the form of the nutrient measured, and interactions with other nutrients (Westermann and Kleinkopf, 1985). The critical nutrient range generally decreases with plant age, possibly being explained by the declining absolute growth rate of plants as they become larger and older (Westermann and Kleinkopf, 1985).

The major soils in Iran are calcareous. Soils deficient in micronutrients, such B, Cu, Fe, Mn and Zn, are widespread in Iran. Zinc is essential for both plants and animals because it is a structural constituent and regulatory co-factor in enzymes and proteins involved in many biochemical pathways. Millions of hectares of cropland are affected by Zn deficiency and approximately one third of the human population suffers from an inadequate intake of Zn (Alloway 2009). Studies conducted on crops have shown a negative correlation between soil pH and metal uptake (Wang *et al.* 2006). Zinc deficiency in soils and plants is a global micronutrient deficiency problem reported in many countries. Low solubility of Zn in soils rather than low total amount of Zn is the major reason for the widespread occurrence of Zn deficiency problem in crop plants (Alloway 2004; Cakmak 2008). Among the micronutrient disorders, Zn deficiency continues to be a limiting factor in crop production in many states of Iran. Its deficiency in field crops is so widespread that it ranks next in its importance to N and P (Bansal *et al.* 1990). Severe Zn deficiency symptoms with corresponding decreases in yield, especially of cereals, were found mainly in crops grown on calcareous soils of arid and semi-arid regions (Takkar and Walker, 1993). Iran is one of the major maize-producing countries in the world. Deficiency of Zn in maize occurs in many parts of the world where the available Zn status of soils is very low, such as on calcareous soils (Aref 2010a; Aref 2010b). The main soil factors controlling the amounts of plant-available forms of Zn in soils include: the ‘total’ Zn content, pH and redox conditions, calcite ($CaCO_3$) and organic matter contents, concentrations of all ligands capable of forming organo-Zn complexes, microbial activity in the rhizosphere, concentrations of other trace elements, concentrations of macro-nutrients (especially P) and the soil moisture status (Alloway 2009).

Boron requirements for plant growth vary with plant species (Bell 1997). For example, in wheat, the youngest emerged leaves expanded normally even though the leaves had less than 2 mg B kg^{-1} dry matter (Huang *et al.*

1996). According to some authors, B deficiency is one of the most widespread of all micronutrient deficiencies (Sillanpaa 1982). In many parts of the world, B deficiency is the most widespread micronutrient problem in eucalypt plantations (Sakya *et al.* 2002). Plant responses to B have been reported to be influenced by environmental factors (Rerkasem and Jamjod, 1997).

Nitrogen fertilization is one of the factors that most contributes to an increase in dry matter production of corn (Bernardi *et al.* 2009). N is required for all stages of plant growth and development because it is the essential element of both structural (cell membranes) and nonstructural (amino acids, enzymes, protein, nucleic acids and chlorophyll) components of the plant (Seilsepour and Rashidi, 2011).

Corn leaves have a high concentration of N when they first emerge, but the N concentration can decrease rapidly as the plant grows. This happens because the plant has the ability to move N from older tissue to younger tissue. Therefore, the N analysis you receive from the lab will vary depending on which leaf was submitted (Schwab *et al.* 2011). Nitrogen-deficient plants exhibit slow stunted growth, and their foliage is pale green. Deficiency symptoms generally appear on the bottom leaves first. In severe cases, the lower leaves have a “fired” appearance on the tips, turn brown, usually disintegrate, and fall off. Nitrogen deficiency can be corrected with an application of N fertilizer. Crop response to fertilization with N is generally very prompt, depending on the source of N, stage of plant growth, rainfall and temperature (Tucker 1999).

Iran soils tend to be high in pH and calcium carbonate, both of which reduce P solubility and availability to plants. Phosphorus is used in the plant for energy storage and transfer, maintenance and transfer of genetic code, and is structural component of cells and many biochemicals In soil solutions and plants (Marschner 1995). Phosphorus can bind to Zn thus forming insoluble zinc-phosphate complexes. This in turn would inhibit both the uptake of Zn by the root and the movement of Zn in the plant (Kizilgoz and Sakin, 2010). High concentrations of P in soil solutions can reduce solubility of Zn; similarly, high concentrations of P in the plant can reduce Zn concentration and hence induce Zn deficiency (Marschner 1995). The soils of Iran are inherently low in fertility and P deficiency is regarded as the most limiting soil fertility factor for corn production and its application is therefore a major nutritional constraint to Zn uptake of corn in the arid and semiarid zone of Iran (Aref 2010a; Aref 2010b). Due to biochemical functions of phosphours in the plant, the most important of which is the activation of enzymes participating in generating and transformation of energy as well as the synthesis of carbohydrates, proteins and fats, this component controls N metabolism (Potarzycki 2009). Phosphorus translocates from older tissue to new, actively growing tissue quite readily, so discoloration tends to appear on older tissue first. Phosphorus deficiency is often difficult to diagnose correctly from visual symptoms alone. Soil and plant tissue analyses are required to confirm this deficiency (Hodges 2010). Phosphorus deficient plants are characterized by stunted growth, dark green leaves with a leathery texture, and reddish purple leaf tips and margins. Reddish purple margins are characteristic of P deficiency on corn. Symptoms usually occur on young plants when the soil temperature is below 16^{o}C (Tucker 1999).

Potassium is one of the important macronutrients next to N and P. This nutrient is one of the essential nutrients whose deficiency affects the crop growth and production. Potassium is an activator of many plant enzymes. Potassium has important functions in plant water relations where it regulates ionic balances within cells. Potassium regulates the leaf stomata opening and subsequently the rate of transpiration and gas exchange. Plants also need K for the formation of sugars and starches, for the synthesis of proteins, and for cell division. It increases the oil content of pistachios and contributes to its cold hardiness (Beede *et al.* 2011). Mild K deficiency in crops does not immediately result in visible symptoms because of the high rate of redistribution between mature and developing tissues. At first there is only a reduction in growth rate (hidden hunger) and only later do chlorosis and necrosis begin in the more mature leaves. In many crop species including maize and fruit trees these symptoms begin in the margins and tips of the leaves but in others including some legumes irregularly distributed spots occur on the leaves (Mengel and Kirkby, 2001). Under K deficient conditions photosynthesis is depressed as a consequence of sucrose accumulation in the leaves and its effect on gene expression (Hermans *et al.* 2006; Romheld and Kirkby, 2010).

Therefore, the objective of this work aims to investigate the effect of Zn and B on the NPK nutrition of maize in a calcareous soil with low Zn and B availability.

MATERIALS AND METHODS

A two-year field experiments were conducted in the agricultural farm of Aref in Abadeh Tashk, Fars province of Iran in 2009 and 2010 growing seasons to determine the response of maize (*Zea mays* L.) to different methods and levels of Zn and B fertilization on leaf NPK concentrations. The region studied is geographically located in calcareous soil zone in the northeast of Fars province 200 km from the Shiraz with latitude 29° 43' 44" N and longitude 53° 52' 07" E and 1580 m altitude.

Composite soil sample, obtained from 0-30 cm depth was collected from the site before land preparation and used to characterise the soils at the sites. The soil sample was air-dried, ground, sieved and analyzed for following properties. The physical and chemical properties of the soil are given in Table 1. Soil pH analyzed at

1:2.5 soil-water ratio, was determined electrometrically (Van Lierop 1990). The electrical conductivity was determined in saturated extract. Soil texture was determined by the hydrometer method (Gee and Bauder, 1986). Organic carbon was determined using Walkley-Black procedure (Nelson and Sommers, 1982). Soil available K was determined by 1 M NH_4OAc extraction and K assessment in the extract by flame photometer (Thomas 1982). Soil available P was measured using the Olsen method (Olsen and Sommers, 1982). Extractable Fe, Mn, Zn and Cu were extracted using DTPA solution and measured by atomic absorption spectrometry (Lindsay and Norvell, 1978). Boron was extracted with hot water and measured by Azomethine-H colorimetric method (Bingham 1982).

The experiments were laid out in a two factorial arrangement in a randomized complete block design and replicated three times. The treatments consisted of 5 levels of Zn fertilizer (0, 8, 16 and 24 kg ha^{-1} Zn added to the soil and Zn foliar spray with a 0.5 percent concentration) applied as zinc sulfate and 4 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) applied as boric acid. 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. There was a space of 70 cm between plots and 2.5 m between replications. Seed of corn (cv. single cross 401) was sown as furrow system. The basal fertilizer applications were 180 kg ha^{-1} N as urea (with 46% N), 70 kg ha^{-1} P as triple super phosphate (with 46% P_2O_5) and 75 kg ha^{-1} K as potassium sulfate (with 50% K_2O). Fertilizers of P and K used before sowing but half of the urea was used when sowing 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 0.5% zinc sulfate and 0.3% boric acid two times: one at vegetative growth stage and the other after corn ears formation.

Leaf samples were collected from the second and third leaves from the top of plant at the silking corn growth stage from all plots and analyzed for total N, P and K concentrations. The samples were washed with distilled water, dried in a forced air oven at 70^{o}C for 48 hours 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, leaf N was determined using the micro-Kjeldahl digestion method, P by spectrophotometer and K by flame photometer.

The obtained data of nutrient analysis were statistically analyzed using SAS computer software (SAS 2001). The Duncun's multiple range test was also performed to identify the homogenous sets of data.

RESULTS AND DISCUSSION

Physical and chemical characteristics of soil

Soil test results from soil samples taken in the spring of 2009 are presented in Table 1. A good test should account for all factors that influence plant availability and uptake, including soil characteristics such as type of minerals, soil pH, and conditions for root growth. Estimating all these factors appropriately is not an easy task (Mallarino and Sawyer, 2000). The experimental soil was loam in texture and it had following characteristics: pH 8.2, EC 2.41 dS m^{-1} and organic carbon 0.49%. Available micronutrients extracted by DTPA (as mg kg^{-1}) were Zn 0.32, Fe 1.65, Cu 0.62, Mn 8.14 and B 0.78. Soil available P and K were 12.1 and 229 mg kg^{-1}, respectively.

The value of a soil analysis as a guide to fertilization practices is limited by the inability to predict the relationship between soil chemical analysis and plant nutrient uptake. Soil analysis is best suited for assessment of pH, saturation percentage, CEC, and salinity (Beede *et al.* 2011).

The soil available K was above the critical level but available P was low. Phosphorus deficiency symptoms may appear when soil P levels are adequate. When soil is cool, less P is available for plant uptake, whether or not an adequate amount is present. Symptoms related to cool weather generally disappear as soil temperature increases. Some corn growers apply a starter fertilizer containing P to offset the effects of cool weather during early season growth (Tucker 1999). While soil P tests are useful in determining the long-term fertilizer requirements of crops, plant P tests are necessary to correct the nutrient deficiency of the current crops. Under rainfed agriculture, the plant P tests become further necessary for achieving economic yields of crops because fertilizer use is generally not adequate for achieving the potential maximum yields (Sahrawat *et al.* 1999). Low levels of plant-available P are a limiting soil-fertility factor under the conditions of southern Iran. Increased P fertilization is usually recommended to improve these soils (Aref 2010a; Aref 2010b; Aref 2011). The availability of soil K depends on process and dynamic of K in soil especially sorption and desorption processes. If nutrient concentration in soil solution increased because of fertilizer application, the nutrient was immediately absorbed by soil into temporary non available form; this process was called sorption. If the nutrient concentration in soil solution decreased due to absorption or leaching, the absorbed nutrients were released in solution and absorbed by plant; this process was called desorption (Brady 1984; Nursyamsia *et al.* 2008).

The nutrients levels of K and Mn were adequate at the experimental site but the P, Zn, B, Fe and Mn were below the critical level. Nable *et al.* (1997) reported that soils containing more than 5 to 8 mg L^{-1} of hot water soluble B is considered to probably cause B toxicity. Natural soils derived from marine evaporates contain a great concentration of B. In addition, irrigation water and industrial sources of B may also play an important role in increased B level in cultivable soils (Nable *et al.* 1997; Rajaie *et al.* 2009). Sims and Johnson (1991) expressed that B critical levels are 0.1-2.0 mg kg^{-1} for different crop plants. The critical DTPA extractable Zn concentration was shown to be 0.9 mg Zn kg^{-1} soil (Ziaeian and Malakouti, 2001).

Table 1. Initial analysis of 0-30 cm soil depth from maize experimental site

Depth of soil (cm)	Soil texture	pH	EC (dS m^{-1})	Organic carbon (%)	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

Most sandy soils (coarse texture) are deficient in micronutrients. Clay soils (fine texture) are not comparatively to be low in plant available micronutrients. The study indicates that there is a positive correlation of clay contents with Fe, Cu, Zn and B (Nazif *et al.* 2006) studied that available Mn and Fe decreased with soil pH and available Cu increased with clay and organic carbon content and available Fe decreased with sand content (Chhabra *et al.* 1996).

Optimum ranges of Mn for all soil textures are 11-20 mg kg^{-1} Mn. For high organic matter soils, Mn soil test category is based on soil pH values: >6.9 is low; 6.0 – 6.9 is optimum; < 6.0 is high (Sturgul 2010). Iron is an essential element for plants. However, low availability of soil-Fe to plant roots is generally restricted in alkali soils because of their high pH and high bicarbonate concentrations that lower the solubility of Fe and reduce its uptake by plant roots especially for Strategy I plant species dependent on inducible ferric reductases for cellular Fe transport (Jeong 2009; Zuo and Zhang, 2010). Results of different researches in Iran show that critical levels of Fe, Mn, Zn, Cu (DTAP method) and B (Hot water method) are 4-4.5, 3.6-4.6, 0.75-2, 0.87-1.1 and 0.65 mg kg^{-1} soil, respectively, for wheat (Balali *et al.* 2000; Feiziasl *et al.* 2009; Feiziasl *et al.* 2003).

Leaf N concentration

The obtained results in Table 2 show that the effects of Zn, B and Zn-B interaction on the leaf N concentration were insignificant (P< 0.05). The P and B available in the soil were low therefore the leaf N concentration didn't change by B and Zn application. Because Chatterjee *et al.* (1990) observed that P deficiency causes increase in protein solubility, ribonuclease, acid phosphatase, and polyphenol oxidase activities which were intensified by a combined deficiency of B and P.

The availability of nutrients influences plant growth and can determine community structure. It is possible to generalize about the response of plants to limited amounts of most nutrients. However, there are species and community specific responses and adaptations that enable plants to cope with specific nutrient limitations (Evans and Edwards, 2001). The results of this study are contradiction with Bonilla *et al.* (1980) who studied the effects of deficient and toxic levels of B on various aspects of N metabolism in sugar beet and stated that plant analysis shows a nitrate ion accumulation, a decrease in the activity of the nitrate reductase enzyme and lower molybdenum absorption. Also, Hellal *et al.* (2009) stated that foliar application of B significantly increased the N content of sugar beet root and it has no significant effect on shoot N; in fact the synergetic effect found between B and N acting increase in N contents in root and shoot tissues.

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

B (kg ha^{-1})	Zn (kg ha^{-1})					
	0	8	16	24	Zn foliar spray	Mean of B levels
0	2.33 a	2.24 a	2.18 a	2.25 a	2.27 a	2.26 a
3	2.18 a	2.31 a	2.21 a	2.22 a	2.27 a	2.24 a
6	2.22 a	2.35 a	2.14 a	2.28 a	2.23 a	2.24 a
B foliar spray	2.18 a	2.35 a	2.20 a	2.17 a	2.34 a	2.25 a
Mean of Zn levels	2.23 a	2.31 a	2.18 a	2.23 a	2.28 a	

The same letters are not significantly different in each row or in each column (p<0.05) by Duncan's test

The mean leaf N content in this study was below the critical level according to the other researches; so that, Plank (1989) reported that N sufficiency levels for corn in whole plants less than 30 cm tall, leaf below whorl plants more than 30 cm tall and ear leaf at tasseling before silks turn brown were 3.5-5.0%, 3.00-3.50% and 2.75-3.00%, respectively. Critical values are crop specific, It is essential that the nutrient recommendations supplied by the testing laboratory reflect comparison to the adequate and critical values for corn, since nutrient requirements can differ significantly between crops (Beede *et al.* 2011). For medium and fine-textured soils, N recommendations are based on soil yield potential and organic matter content (Bundy 1998). The concentrations of N, P and K in ear leaf samples of initial silk of maize are 2.76-3.50 %, 0.25-0.50 % and 1.71-2.50 %, respectively (Vitosh *et al.* 1994). The actual composition varies between plant organs and depends on species and growth conditions, but the important feature to note is the difference between the 6 macronutrients N, K, Ca, Mg, P and S and the micronutrients (Evans and Edwards, 2001).

Leaf P concentration

The obtained results in Table 3 show that, the Zn application significantly increased ($p<0.05$) the P contents in leaf of corn grown in calcareous soil. Application of 16 kg ha^{-1} Zn significantly increased the P content in leaf of corn relative to control treatment. Therefore a synergism was seen between Zn and P. The P-Zn interaction is among the most widely reported and studied of these interactions. Similar observations of increased the leaf P content with soil application of Zn have been made by Zhu *et al.* (2001). It has been widely reported that Zn deficiency may be associated with an increase in P uptake and/or tissue P concentration, and it can cause P toxicity in hydroponic culture (Zhu *et al.* 2001). Phosphorus interactions with micronutrients have been reported on a wide variety of crops. Interactions with P have been reported for B, Cu, Fe, Mn, Mo, and Zn. Nutrient accumulation studies in corn have found P and Zn uptake, translocation, and deposition patterns to be quite similar. Although P interacts with many nutrients, the most commonly observed and studied antagonistic interaction is with Zn (Barben *et al.* 2007). Zinc is absorbed by plants as Zn^{2+} and P absorbed as $H_2PO_4^-$ or HPO_4^{2-}. Positively and negatively charged ions have an electrical attraction to one another, facilitating the formation of a chemical bond in either the soil or the plant tissue (Barben *et al.* 2007). Although, applying Zn to the soil increased the P concentration in corn leaf but more studies showed an antagonistic relationship between Zn and P. Webb and Loneragan (1990) argued that the enhanced P uptake in Zn-deficient plants was mediated primarily through the concentration of Zn in shoots and roots.

The minimum mean leaf P concentration, 0.34%, was obtained at no Zn level. The highest mean leaf P content, 0.38%, was seen at 16 kg ha^{-1} Zn level. Other Zn levels showed no significant effect on the leaf P concentration relative to the zero Zn level also Zn spraying had any significant effect on it. The main effect of B on the leaf P content was significant ($p<0.05$). The maximum mean leaf P concentration, 0.37%, was seen at zero B level. The use of 3 kg ha^{-1} B and B spraying reduced the P concentration in corn leaf; of course, there was no significant difference between the B levels added to the soil with B spraying level. Therefore, an antagonism was seen between B and P. Similar results reported by other researches. Chatterjee *et al.* (1990) observed that P deficiency i.e., (soluble protein, DNA, activity of ribonuclease and increase activities of peroxidase, acid phosphatase and polyphenol oxidase) were intensified by a combined deficiency of B and P. On the other hand, decrease in (starch, sugar content, DNA, RNA and activity of ribonuclease) were aggravated by a combined excess of B and P (Tariq and Mott, 2007). Also, reduction in leaf concentration of P can be attributed to a dilution effect (Ziaeyan and Rajaie, 2009).

Examination of the effect of Zn-B interaction on the leaf N content showed that the use of B at high Zn level (24 kg ha^{-1}) reduced the leaf P content but at other Zn levels showed no significant effect on it; in fact high amount of Zn in the soil assisted to decreasing of leaf P concentration by B use. The use of Zn at high B level (6 kg ha^{-1} B) increased the leaf P content but at low B levels (0 and 3 kg ha^{-1} B) and B spraying level showed no significant effect on the leaf P content. In fact, the presence of a high amount of B in the soil assisted to increasing of leaf P content by Zn application. The results of this study are contradiction with other findings. Huang *et al.* (2000) demonstrated that Zn deficiency causes an increase in the expression of P transporter genes in both P-deficient and P-sufficient barley roots. Phosphorus availability in calcareous soils is almost always limited. The P concentration in the soil solution is the factor most closely related to P availability to plants. The sustainable concentration is related to the solid forms of P that dissolve to replenish soil solution P following its depletion by crop uptake (Obreza *et al.* 2009). As suggested by (Welch *et al.* 1982) Zn is necessary for root cell membrane consistence and in this function, Zn prevents excessive P uptake and its transport from roots to shoots.

The lowest P concentration in the corn leaf, 0.32%, was obtained by joint use of Zn and B foliar spray. According to the other findings, P concentration in corn leaf was sufficient for corn. The amount of a specific nutrient for a particular crop that is adequate for growth varies across the season. The concentration of many nutrients decreases as the crop matures (Steinhilber and Salak, 2010). The critical level, low range and sufficient range of P concentration in ear leaf at early silk is 0.20%, 0.20-0.22% and 0.22-0.30% respectively (Olsen's Agricultural Laboratory, 2010). Steinhilber and Salak (2010) stated that the amount of a specific nutrient that is sufficient or adequate for plant growth varies from crop to crop. Sufficiency ranges of N, P and K for corn are 2.70-4.00%, 0.25-0.50%, and 1.70-3.00%, respectively. Olsen's Agricultural Laboratory (2010) classified P concentration in whole plant from seedling to 6th leaf stage and fully expanded leaf prior to tasseling as: 0.22% (critical level), 0.22-0.25% (low), 0.25-0.50% (sufficient); and for K as: 2.25% (critical level), 2.25-2.50% (low) and 2.50-4.00% (sufficient).

Table 3. The effect of Zn and B on the leaf P concentration (%)

B (kg ha^{-1})	Zn (kg ha^{-1})					
	0	8	16	24	Zn foliar spray	Mean of B levels
0	0.36 abc	0.37 abc	0.37 abc	0.39 a	0.37 abc	0.37 a
3	0.34 bc	0.35 bc	0.36 abc	0.34 bc	0.34 bc	0.35 b
6	0.35 bc	0.35 bc	0.41 a	0.36 abc	0.35 abc	0.36 ab
B foliar spray	0.33 c	0.37 abc	0.36 abc	0.35 bc	0.32 c	0.35 b
Mean of Zn levels	0.34 b	0.36 ab	0.38 a	0.36 ab	0.35 b	

The same letters are not significantly different in each row or in each column ($p<0.05$) by Duncan's test

Leaf K concentration

The results presented in Table 4 revealed that leaf K concentration increased with soil application of 6 kg ha^{-1} B but other B levels had no significant effect on it. The lowest and the highest mean leaf K content, 2.07 and 2.2%, were seen at 3 and 6 kg ha^{-1} B levels, respectively. The effect of Zn on the leaf K content was insignificant ($p<0.05$). Therefore, there was a synergism between B and K. Potassium is known to interact with almost all of the essential macronutrients, secondary nutrients, and micronutrients. The results of the study are contradiction with Wuding *et al.* (1987) who studied interaction between B and K in cotton nutrition and stated that there was no difference in K content of leaves at any given B levels in soil, but total K absorbed by the plant decreased at low B and high B levels.

Interaction of Zn and B on the leaf K content was significant ($p<0.05$). Nutrient interaction in crop plants is probably one of the most important factors affecting yields of annual crops. Nutrient interaction can be either positive, negative or neutral (Fageria and Baligar, 1997). It can be measured in terms of crop growth and nutrient concentrations in plant tissue. Soil, plant and climatic factors can influence interaction. In the nutrient interaction studies, all other factors should be at an optimum level, except the variation in level of the nutrient under investigation (Fageria 2002).

The use of 6 kg ha^{-1} B at zero Zn level increased the leaf K content from 1.96 to 2.41% but other B levels had no significant effect on it. At 8 kg ha^{-1} Zn level, only application of 3 kg ha^{-1} B increase leaf K content. At other Zn levels, applying B to the soil and spraying it showed no significant effect on the leaf K content. Foliar spray of B in any Zn levels has no significant effect on the leaf K content. Therefore, with increasing of Zn content, the higher rate of B was needed for increasing K concentration in the leaf by B application. In fact, no Zn content helped increasing leaf K content, but presence of Zn prevented from increase of leaf K content.

Zinc application at no B level increased the leaf K content and at 6 kg ha^{-1} B level reduced it but at other B levels had no significant effect on the leaf K content. The use of 8 and 16 kg ha^{-1} Zn at zero B level increased the leaf K content from 1.96 to 2.21 and 2.16%, but there was no significant difference between these two Zn levels. Also, Zn spraying at no B level increased leaf K content from 1.96 to 2.18% but showed no significant difference relative to applying Zn to the soil.

Table 4. The effect of Zn and B on the leaf K concentration (%)*

B (kg ha^{-1})	Zn (kg ha^{-1})					
	0	8	16	24	Zn foliar spray	Mean of B levels
0	1.96 c	2.21 b	2.16 b	2.09 bc	2.18 b	2.12 bc
3	2.05 bc	1.97 c	2.05 bc	2.14 bc	2.12 bc	2.07 c
6	2.41 a	2.19 b	2.06 bc	2.19 b	2.18 b	2.20 a
B foliar spray	2.09 bc	2.13 bc	2.22 b	2.16 b	2.19 b	2.16 ab
Mean of Zn levels	2.13 a	2.12 a	2.12 a	2.15 a	2.17 a	

The same letters are not significantly different in each row or in each column ($p<0.05$) by Duncan's test

The lease K concentration in the leaf, 1.96%, was obtained at control treatment (no Zn and B use). The maximum leaf K content, 1.96%, was recorded by the soil application of 6 kg ha^{-1} B; showing a 23% increase as compared with the control. The mean leaf K concentration in this study was lower than critical level. Range of Sufficient K Concentrations in Cereals at young shoots 5–8 cm above soil surface is 35-55 mg K g^{-1} DW (Barker and Pilbeam, 2007). According to other findings K sufficiency range for corn in whole plant at seedling stage (<10 cm) is 3.0-4.0%, in uppermost mature leaf at vegetative stage is 2.0-3.0%, and in ear leaf at tasseling stage is 1.8-3.0% (Schwab *et al.* 2011). The mineral composition of a leaf is dependent on many factors, such as its stage of development, climatic conditions, availability of mineral elements in the soil, root distribution and activity, irrigation, etc. Leaf samples integrate all these factors, and provide an estimate of which elements are being adequately absorbed by the roots. The main limitation with leaf analysis is that it does not tell us why the nutrient is deficient (Beede *et al.* 2011). Critical nutrient concentration is defined as the concentration of a specific nutrient within a specific plant part at which growth or yield begins to decline. According to this approach, a single concentration value is assigned to a point where the plant nutrient shifts from deficient to adequate. Because of variations in the soil, climate, and other production environments, a range of concentrations is also used to represent critical nutrient concentration (Yin and Vyn, 2004). This would seem to suggest that some factors other than the concentration of K and Ca are involved in the uptake mechanisms of these ions (Tariq and Mott, 2006).

CONCLUSION

The results of this study showed that concentrations of N and K in the corn leaf were below the critical level but leaf P concentration was sufficient. A synergism was seen between Zn-P and between B-K and an antagonism between B-P. The presence of a high amount of B in the soil assisted to increasing of leaf P content by Zn application. With increasing of Zn content, the higher rate of B was needed for increasing K concentration in the leaf by B application.

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