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RESEARCH ARTICLE

Physiological and Biochemical Response of Maize (*Zea mays* L.) to Exogenic Application of Boron under Drought Stress

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Abstract

An experiment was conducted at the Agronomic Research Area, University of Agriculture, Faisalabad, during autumn 2011 to determine the response of maize to foliar application of boron under water stress conditions. The experimental site is located at 73.09^0 E longitudes, 31.25^0 N latitudes with semi-arid and sub-tropical climate. Foliar spray showed a non-significant effect on water relations parameters. No significant interaction was found among stress levels and treatments. Stress levels showed significant differences in P concentration. Imposition of water stress significantly reduced the leaf K^+ concentration in contrast with boron foliar application which increased its concentration.The results showed that water stress and boron foliar application both significantly affected phosphorus contents. Stress levels were significantly varied in B concentration. Application of boron significantly affected the stem amylase activity in both S_1 and S_2 stress level and interaction among the stress levels and boron foliar application was non-significant. The effect of stress levels on stem amylase concentration was non-significant. A significant effect of boron foliar application was observed on stem protein concentration in all stress levelswhile interaction among the stress levels and boron foliar application was non-significant.The effect of stress levels on stem protein concentration was non-significant. Application of B significantly affected the stem total soluble sugars in both stress levels S_1 and S_2 while interaction among the stress levels and boron foliar application was non-significant.

Introduction

Maize (*Zea mays* L.) is the highest yielding cereal crop in the world and holds a prominent position in major crops of Pakistan. It is the third most important cereal crop after wheat and rice in worldand sown under both irrigated and rain fed conditions of almost all the provinces of Pakistan. Punjab and NWFP are the major producers. Maize is being grown an area of 1118 thousand hectares with annual production of 4036 thousand tones (GOP, 2009).

Drought limits maize crop productivity worldwide (Sajedi*et al*., 2009; Bastos*et al*., 2011). Pakistan is a water stressed country with per capita water availability of little over 1000 m^3 per year (Araus*et al*., 2002). Of all the relevant factors that affect its growth and development, drought is the most significant cause of severe yield reductions (Ribaut*et al*., 2009). Drought influences the physiology and metabolism of crops, impairs photosynthetic machinery and other yield-determining physiological processes, and eventually lowers production (Farooq*et al*., 2009; Malik and Ashraf, 2012). When the plant is subjected to drought stress, the permeability of the cell membrane increases and several types of reactive oxygen species (ROS) are induced, disrupting the balance between the production of ROS and the antioxidant defense (Yuan *et al*., 2010). Drought stress causes a reduction in photosynthesis. It also influences water balance and disrupts carbohydrate metabolism (AlGhamdi, 2009).Water stress has been found to reduce leaf area; photosynthesis, leaf chlorophyll contents and consequently grain yield (Rotundo*et al*., 2006). Maize is apparently more drought resistant in the early stages of growth than when fully developed (Khan *et al*., 2001).Water stress also affects the availability of nutrients for plant growth and development. Both deficiencies and toxicities of micronutrients can suppress plant growth and yield. Maize is the kind of plant especially sensitive to micronutrients insufficiency and the first plant to prove indispensability of micronutrients for plants (Broadley*et al*. 2007). Supplementation of microelements improves the plant growth and development (Kulczycki*et al*. 2008).

Boron is an essential micronutrient for plant growth and reproduction. It is important for carbohydrate metabolism and translocation (Siddiky*et al*., 2007) and also plays an indispensable role in plant cell formation, integrity of plasma membranes, pollen tube growth and increases pollination and seed development (Oosterhuis, 2001). After zinc boron is second most widespread deficient micronutrient in paddy soils of Pakistan (Shorrocks, 2006).

Boron (B) is essential for normal growth and development of all plants (Brown *et al*., 2002). It plays an important role in the growth and development of new cells in the plant meristems because it is closely associated with cell division and in the growth regions of the plant that is near the tips of roots and shoots. It is also needed for the growth of the pollen tube during flower pollination and is therefore important for good seed set and fruit development (Havlin*et al*., 2005). Boron is thought to increase nectar production by flowers, and this attracts pollination insects. Additionally, boron has a role in the cell structure. Tissue of boron deficient plants often breaks down permanently, causing brown flecks, necrotic spots, cracking and corky areas in fruits and tubers (Dear and Weir, 2004). Pakistani soils are deficit in micronutrients inclusive of B because of their alkaline-calcareous nature, low organic matter content, nutrient mining with intensive cropping and inadequate and imbalanced fertilizer use resulting in low availability of micronutrients (Rashid *et al*., 2002). Soil application of micronutrient is not very effective to recover these deficiencies in calcareous and alkaline soils due to mass flow of micronutrients (Zekri and Obereza, 2003). The alternate way is to supply micronutrients fertilizers through foliar spray. Foliar spray of boric acid (H_3BO_3) has been reported to be more effective than soil application for fulfilling B requirements and curing its deficiency in maize. Although correction of B deficiency can be achieved through soil or foliar B applications, foliar treatments are more effective under dry conditions due to the low root absorption rates from dry soils (Rufat and Arbones, 2006).

Keeping in view, the low availability of micronutrients in our soils, it becomes necessary to supply micro nutrient in required amount through appropriate methods to raise maize productivity. Foliar spray is hypothesized as a possible solution. At present little is known about the effect of B foliar application on growth and yield of maize under water limited conditions. Therefore, the present study was focused to elucidate the effect of different boron levels and their interactive effect on physiological and biochemical parameters of maize (*Zea mays* L.).

Materials and Methods

Experimental Site and Conditions:

A current study was conducted at the Agronomic Research Area, University of Agriculture, Faisalabad, during autumn 2011 with the objective to determine the response of maize to foliar application of boron under water stress conditions The experimental site is located at 73.09^0 East longitudes, 31.25^0 North latitudes and at altitude of 135 meters above sea level with semi-arid and sub-tropical climate. The soil of experiment site was sandy loam in texture (Table 1).

Experimental Design and Treatments:

The experiment was laid out in RCBD with split plot arrangement and four replicates. The experiment comprised of the following treatments:

A= stress levels (S)

S_1= No stress (Fully irrigated)

S_2= water stress of 15 days (imposed at the onset of tasseling stage)

B=foliar spray (F)

Foliar sprays were applied at tasseling stage

F_1= no spray

F_2= simple water spray

F_3= boron spray @ 100 ppm

Exogenicapplication:

Solutions with different concentrations of the B and water were sprayed in the respective plots at the stages where the stress was induced. All the analysis was done according to the method given in Hand Book No. 60 (US Salinity Lab. Staff, 1954).

Physiological Parameters:

Leaf water potential

The upper most fully expended sunlit leaves of two plants from each treatment were used for measuring leaf water potentialwith a Shetlander type pressure chamber (Turner, 1981).

Leaf osmotic potential

The same leaf, as used for water potential measurement, was frozen in a freezer at -20^0C for seven days and then the frozen leaf material was thawed and cell sap extracted with the help of a disposable syringe. The sap so extracted was directly used to determine the osmotic potential by using an Osmometer (wescor 5500).

Leaf turgor potential

Leaf turgor potential was calculated as the difference between osmotic potential and water potential values.

Ionic Analysis

Leaf nitrogen (%)

Leaf nitrogen was determined according to Chapman and Pratt (1961) method, which involved digesting the plant material with concentrated sulphuric acid (H_2SO_4) and digestion mixture, comprising K_2SO_4, $CuSO_4$ and $FeSO_4$ in ratio of 10:0.5:1. For the quantity of acid used in titration, the percentage of element nitrogen was calculated by using the formula;

$$N (\%) = \frac{(V-B) \times N \times R \times 14.01 \times 100}{Wt \times 1000}$$

Where:

V	=	Volume of N/10 H_2SO_4 titrated for the sample (ml).
B	=	Digested blank titration volume (ml).
N	=	Normality of H_2SO_4 solution.
R	=	Ratio between total digested volume and distillation volume.
Wt	=	Weight of dry plant sample (g).
14.01	=	Atomic weight of N.

Leaf Potassium (%)

Potassium was determined by flame photometer according to the method described by Chapman and Parker (1961). Quantity of element was estimated in ppm by comparing the emission of flame photometer with that of standard curve which was then converted into percentage by using the following formula.

$$K (\%) = \frac{\text{ppm on graph} \times \text{dilution} \times 100}{10^6}$$

Leaf Phosphorus (%)

Phosphorus was determined according to the method described by Chapman and Pratt (1961). The samples were fed in spectrophotometer at a wave length 420 nm and transmittance was noted which was compared with that of standard curve to find out the quantity of the element in ppm which was then converted into percentage by using the following formula.

$$P (\%) = \frac{\text{ppm on graph} \times \text{dilution} \times 100}{10^6}$$

Boron (mg/g) in leaves

The boron in leaves was determined by dry ashing and subsequent measurement of B by colorimeter using Azomethine-H. Samples were run on a spectrophotometer and standard curve was prepared by plotting absorbance against the respective B concentrations. The B concentration in the unknown samples was read from the calibration curve. Then the B was calculated according to the following formula:

B (ppm) = ppm B (from calibration curve) ×A/ Wt.

Where:

A = Total volume of the extract (ml)

Wt. = Weight of dry plant (g)

Biochemical analysis:

Protein content determination (ug/g)

The soluble proteins of the samples were determined by Bradford method (Bradford, 1976). 50 uL of the sample was taken in micro centrifuge tube and 2 Ml of Bradford reagent was added. Blank contains Bradford reagent. Absorbance was noted at 595 nm. Protein content was determined by standard curve prepared with different concentrations of bovine serum albumin (BSA).

Amylase (I.U/g)

Amylase activity was determined using the modified method was reported by Varavint*et al*, *(*2000). 0.1 mL of the stored extract was taken and 1.5 Ml, 2% soluble potato starch solution containing 500 ppm of calcium ion (cofactor) and 1 ml of 100 M*m* tri (hydroxyl methyl amino methane/HCL buffer) pH 7 was added. The mixture was incubated in a water bottle with constant shaking at 40 C for 15-30 min. The reaction was stopped by adding 1 ml of 3, 5-dinitrosalisylic acid, followed by boiling for 10 min to develop brown color. The final volume was made to 5 ml with dist. Water and absorbance was measured at 540 nm.

Total soluble sugars (mg/ml)

To determine total soluble sugars content, a modified method given by Sadasivam and Manickam (1992) was used. The amount of soluble sugars in the sample was calculated using a standard graph prepared by plotting concentration of the standard on the X-axis versus absorbance on the Y-axis,

Statistical Analysis

The data were analyzed statistically using Fisher's analysis of variance technique (Steel *et al*., 1997) and significant treatment means were separated using Least Significant Difference (LSD) test at 0.05 probability level.

Results and Discussion

Water relations:

Water potential (Ψ_w), an estimate of plant water statusis useful in dealing with water transport in the soil-plant-atmosphere continuum. The analysis of variance showed that water stress significantly affected this parameter. The comparison of treatments means (Table 2) showed that minimum water potential (-0.323 MPa) was observed where foliar application of boron @ 100 ppm (F_3) was applied, while maximum (-0.340 MPa) was noted where F_2 was applied, value of F_1 is at par with F_2. Minimum water potential (-0.38 MPa) was observed where water stress S_2 was applied while maximum water potential (-0.28 MPa) was noted where S_1 was applied.

Foliar spray showed non-significant effect on water potential. Ashraf *et al*., (2002) investigated the changes in water relations of okra plants in response to water stress and reported that leaf water potential and osmotic potential of drought stressed plants reduced significantly. Saab *et al*., (1990) reported that in arid and semi-arid regions, drought stress usually occurs together with light and high temp, stresses. At low water potentials, primary root of maize continued slow growth with inhibiting shoot growth. Atteya (2003) found that exposure of plants to drought led to noticeable decrease in leaf water potential (WP), relative water content (RWC) and osmotic potential (OP). She reported that water stress changed the relation between leaf water potential and relative water content of all genotypes; consequently the stressed plants had lower water potentials than control at same leaf RWC.

Osmotic potential (Ψ_S) (MPa)

Imposition of water stress significantly reduced the osmotic potential in contrast with boron foliar application which did not affected it. The data regarding to osmotic potential of maize presented in (Table 2) showed that water stress significantly affected this parameter while interaction among stress levels and treatments also showed non-significant behavior. The comparison of treatment means showed that minimum osmotic potential (0.95 MPa) was observed where S_2 was applied while maximum water potential (1.26 MPa) was noted inS_1treatment. Foliar spray showed a non-significant effect on water potential. The comparison of treatment means showed maximum osmotic potential (1.12MPa) in F_1 and F_3treatment (1.11 MPa) while minimum (1.09MPa) was noted in F_3 where foliar application of boron @ 100 ppm was applied.

Turger potential (MPa)

Differences in water relation characteristics reflect the differences between species and cultivars and are considered as an indicator of drought resistance or adaption. As turgor potential is attained by subtracting osmotic potential from the water potential so the results are same like water potential and osmotic potential. Water stress significantly affected turgor potential in contrast with boron foliar application @100 ppm which did not affected it while interaction among stress levels and treatments also showed non-significant behavior.The comparison of treatment means showed maximum turgor potential (0.78 MPa) in F_1 and F_2 treatment while minimum (0.75 MPa) was noted in F_3 where foliar application of boron @ 100 ppm was applied.Stress levels were significantly different in P concentration. Minimum turgor potential (0.55 MPa) was observed where water stressesS_2 was applied while maximum turgor potential (0.99 MPa) was noted where S_1 was applied (Table 2).

Ionic analysis:

Nitrogen (% of dry matter)

A significant effect of boron foliar application and stress levels was observed on leaf N concentration while interaction was non- significant among stress levels and treatments.The comparison of treatments, means (Table 3) shows that maximum leaf N concentration (3.17 % of dry matter) was observed where foliar application of boron @100 ppm (F_3) was applied, while minimum (1.97 % of dry matter) was noted where F_1 was applied, value of $F_2$is at par with F_2.Among stress levels minimum leaf N concentration (2.10% of dry matter) was noted in S_2 and maximum leaf N concentration (2.65% of dry matter) was noted in S_1.It was founded that the application of boron and nitrogen increased significantly the number of grains per cob, 1000-grain weight, grain yield, grain crude protein contents and grain oil content over control. There was an increase of 103.20% in grain yield over control in maize (Ahmad *et al*., 2000).

The decrease in N concentration due to water stress has been reported in various crops including wheat (Singh andUsha, 2003), in soybean and rice (Tanguilig*et al*., 1987) and in maize (Premachandra*et al*., 1990). On the other hand, Sarwar*et al*., (1991) studied the response of different wheat varieties to water stress and reported a significant increase in N content under water stress.

Potassium (% of dry matter)

Imposition of water stress significantly reduced the leaf K^+ concentration in contrast with boron foliar application which increased it while interaction was non- significant among stress levels and foliar spray.The comparison of treatment means showed that maximum leaf K^+ concentration (0.35 % of dry matter) was observed where foliar application of boron @100 ppm (F_3) was applied, while minimum (0.18 % of dry matter)) was recorded where $F_2$was applied, value of F_1 is at par with F_2 treatment (Table 3).

Among stress levels maximum leaf K^+ concentration (0.286% of dry matter) was observed in S_1 (no stress. In the same way Sortiropoulos*et al*., (2006) investigated the effects of boron and NaCl induced salinity on growth and mineral composition of the pear (*Pyruscommunis* L.) root stock OH x F 333 shoots cultured in vitro and found that the concentrations of P, K, Ca, Fe, Mn, and Zn of plants were increased by boron and NaCl concentration of the medium. (Gune*et al*., (2003) found that boron foliar application led to significant increases in both concentrations and uptake of calcium, potassium, iron, manganese, zinc and copper in cotton shoots.Increased accumulation of potassium (K^+) in maize seedlings might have played a significant role in plant survival under drought stress by playing an important role in osmotic adjustment (Voetberg and Sharp, 1991).

Phosphorus (% of dry matter)

The results showed that water stress and boron foliar application both significantly affected phosphorus contents while interaction was recorded non-significant among stress levels and treatments. The comparison of treatments, means Table 2showed that maximum leaf P concentration (0.3475% of dry matter) was observed where foliar application of boron @ 100 ppm (F_3) was applied, while minimum (0.1913% of dry matter) was noted where F_1 was applied. Stress levels were significantly different in P concentration. The comparison of means revealed that maximum P concentration (0.292% of dry matter) was observed in S_1while minimum (0.195 % of dry matter) was noted in S_2 stress level (Table 3). These results are in line with Sortiropoulos*et al*., (2006) who investigated the effects of boron and NaCl induced salinity on growth and mineral composition of the pear (*Pyruscommunis* L.) root stock OH x F 333 shoots cultured in vitro and found that the concentrations of P, K, Ca, Fe, Mn, and Zn of plants were increased by boron and NaCl concentration of the medium. It is well established that plants subjected to water stress can accumulate inorganic solutes e.g., N, P, and K etc. Analysis of macronutrients N, P and K in the maize cultivar clearly indicates that water stress increased the shoot and root potassium (K^+) concentrations in all maize cultivars(Weimberg*et al*., 1982).

Boron (mg/g)

A highly significant effect of boron foliar application was observed on leaf B concentration in all stress levelswhile interaction among the foliar spray and water stress levels was non-significant(Table3). The comparison of treatments, means showed that maximum leaf B concentration (65.10 mg/g) was observed where foliar application of boron @ 100 ppm (F_3) was applied, while minimum (52.05 mg/g) was noted where F_1 was applied. Stress levels were significantly different in B concentration. The comparison of treatments, means showed that maximum B concentration (57.20 mg/g) was observed in S_1 while minimum (55.48 mg/g) was noted in S_2 treatment. Our results match with Ben-Gal(2007) who investigated that foliar application of B resulted in increased leaf B and in decreased root B in radish while B was found in plant tissue of tomato in declining order according to: mature leaves, young leaves, roots and stems. Similarly Boaretto*et al*., (2007) also investigated that the foliar B fertilization increased the leaf B content in sweet orange. The phonological phase of the citrus tree affected the B absorption. The more advanced the plant developing flushes at the spraying, higher was the fruit content on B derived from the fertilizer.

Table 1. Physiochemical analysis of soil

Soil parameter	Value obtained	Determination method
Soil type	Sandy loam	Moodie*et al.* (1959) method
pH	8.3	pH meter
Organic matter (%)	0.95	
Available B(ppm)	0.2	HCL method
Available S (ppm)	7.5	Turbidimetric method
Available K (ppm)	175	Amonium acetate solution method
Total N (%)	0.21	Kjeldhl method
Available phosphorus (ppm)	1	Sodiumbicarbonate method

Table 2. Mean values for physiological parameters in maize affected by boron spray and water stress

Water potential	**Treatments**			
Stress level	**F1**	**F2**	**F3**	**Means**
S_1	-0.2890 a	-0.2890 a	-0.2720 a	-0.28 a
S_2	-0.3910 b	-0.3910 b	-0.3740 b	-0.38 b
Means	-0.3400 a	-0.3400 a	-0.323 a	
Osmotic potential				
S_1	1.2525 a	1.2600 a	1.2875 a	1.26 a
S_2	0.9900 b	0.9375 b	0.9500 b	0.95 b
Means	1.1213 a	1.0987 a	1.1187 a	
Turgor potential				
S_1	0.9785 a	0.9710 a	1.0270 a	0.99 a
S_2	0.5990 b	0.5465 b	0.5760 b	0.57 b
Means	0.7888 a	0.7588 a	0.8015 a	

Means with same letters are statistically non-significant

Table 3. Mean values for ionic analysis in maize affected by boron spray and water stress

Nitrogen (%)	**Treatments**			
Stress level	**F1**	**F2**	**F3**	**Means**
S_1	2.2425 c	2.2925 c	3.4150 a	2.650 a
S_2	1.6975 d	1.6675 d	2.9425 b	2.102 b
Means	1.9700 b	1.9800 b	3.1788 a	
Potassium (%)				
S_1	0.2400 bc	0.2325 c	0.3875 a	0.28 a
S_2	0.1425 d	0.1450 d	0.3125 ab	0.20 b
Means	0.1913 b	0.1888 b	0.3500 a	
Phosphorus (%)				
S_1	0.9785 a	0.9710 a	1.0270 a	0.292 a
S_2	0.5990 b	0.5465 b	0.5760 b	.195 b
Means	0.1913 b	0.1938 b	0.3475 a	
Boron (mg/g)				
S_1	52.052 c	52.037 c	67.522 a	57.20 a
S_2	52.057 c	51.717 c	62.682 b	55.48 b
Means	52.055 b	51.877 b	65.102 a	

Table 4. Mean values for biochemical analysis in maize affected by boron spray and water stress

Amylase (I.U/g)	**Treatments**			
Stress level	**F1**	**F2**	**F3**	**Means**
S_1	0.8232 b	0.9852 a	0.6530 c	0.82 a
S_2	0.8933 ab	0.9888 a	0.5970 c	0.82 a
Means	0.8582 b	0.9870 a	0.6250 c	
Protein (ug/g)				
S_1	9.412 abc	10.171 ab	6.703 d	8.76 a
S_2	9.181 bc	10.774 a	8.035 cd	9.33 a
Means	9.297 b	10.473 a	7.369 c	
Total soluble sugars (mg/ml)				
S_1	178.92 ab	216.43 a	155.23 bc	183.5 a
S_2	170.93 abc	186.96 ab	120.98 c	159.6 a
Means	74.93 ab	201.69 a	138.10 b	

Means with same letters are statistically non-significant
S_1= No stress, S_2= water stress of 15 days, F_1= no spray, F_2= simple water spray, F_3= boron spray @ 100 ppm

<u>Biochemical responses:</u>

Amylase (I.U/g)
Amylase concentration is an important parameter to determine the amount of carbohydrates in the stem. The analysis of variance revealed that foliar application of boron significantly affected the stem amylase activity in both stress levels S_1 and S_2 stress level and interaction among the stress levels and boron foliar application was non-

significant.The comparison of treatment means (Table 4) showed that minimum stem amylase concentration (0.625 I.U/g) was observed where foliar application of boron @100 ppm (F_3) was applied, while maximum (0.987 I.U/g) was noted where F_2 was applied, value of $F_1$is also different from F_2treatment.The effect of stress levels on stem amylase concentration was non-significant. It was noted that both stress levels S_1 andS_2 have sameamylase concentration (0.82I.U/g). Application of boron had increased soluble sugars, proteins, amino acid contents and dry mass in the stem in maize (Saugd, 1998).

Protein (ug/g)

A significant effect of boron foliar application was observed on stem protein concentration in all stress levelswhile interaction among the stress levels and boron foliar application was non-significant.The comparison of treatments, means showed that minimum stem protein concentration (7.36 ug/g) was observed where foliar application of boron @ 100 ppm (F_3) was applied, while maximum (10.47 ug/g) was noted where water spray (F_2) was applied, value of $F_1$is at par with F_2 treatment.The effect of stress levels on stem protein concentration was non-significant. The comparison of treatments, means (Table 4) showed that maximum protein concentration (9.33 ug/g) was observed in S_1while minimum (8.76 ug/g) was noted in S_2 stress level. These results confirm to the findings of Dwivedi*et al*., (2002) who investigated that protein contents of maize grain were increased significantly with the increase of B and Zn. The highest grain yield of 8.59 t $ha^{-1}$was obtained plot fertilized at the rate of 150 kg N and 5 kg B ha^{-1}. Former dose (150+5) gave the highest grain oil content while grain protein contents were recorded maximum in the later dose (150+10) (Rahim *et al*., 2004).Ahmadi*et al*., (2010) found that Protein concentration was increased by water stress and the highest concentration of protein was occurred at mild water stress level. Sajedi*et al*., (2009) found that water deficit stress decreased grain yield 33% in grain filling stage as compared with control.Ge*et al*. (2006) investigated through a systematic study the effects of water stress on the activities of protective enzymes, lipid peroxidation and yield parameters of maize (Zea mays L.). Results showed that, under water stress, the activities of superoxide dimutase (SOD), catalase (CAT), and peroxidase (POD) inleaves and roots increased sharply with water stress. The content of melondialdehyde (MDA) increased by to the severity of water stress. The content of MAD in roots was lower than that in leaves. The content of soluble proteins in roots and leaves decreased with increasing drought stress. The economic yield of maize decreased significantly under water stress. The main factors that caused reduction of yield were the decrease in no of grains per cob and 1000- grain weight.

Total soluble sugars (mg/ml)

Sugars are generally the primary substrates of respiratory metabolism, the respiration rate is closely correlated with the sugar content in plant tissue and soluble sugars play a central role in plant structure and metabolism at a cellular and whole organism levels (Dwivedi, 2000). The analysis of variance revealed thatfoliar application of B significantly affected the stem total soluble sugars in both stress levels S_1 and S_2 while interaction among the stress levels and boron foliar application was non-significant. The comparison of treatments, means showed that minimum stem total soluble sugars concentration (138.10 mg/ml) was observed where foliar application of boron @ 100 ppm (F_3) was applied, while maximum (201.69 mg/ml) was noted where (F_2) was applied, value of $F_1$is at par with F_2 treatment. The effect of stress levels on stem total soluble sugars was non-significant. The comparison of treatments, means shows that maximum stem total soluble sugars concentration (183.5 mg/ml) was observed in S_1 while minimum (159.6 mg/ml) was noted in S_2 (Table 4).Yan *et al*. (2003) conducted an experiment to investigate the effect of boron on carbohydrate assimilation and transformation in wheat. Boron was used @ 0, 0.3, 1, and 10 micro mol L^{-1}. These results revealed that boron free and 0.3 micro mol L^{-1} treatments showed higher soluble sugar content in stem.In the same way results showed that the soluble sugar content in stem was higher in the boron free and 0.3 micro mol L^{-1}treatments (Yan *et al*., 2003). Similar findings were also reported bySaugd (1998) that application of boron on maize (*Zea mays* L.) reduced the soluble proteins, total free amino acids and soluble sugars in the stem. Foliar application of boron was more effective and application of boron alleviated the deleterious effect of water logging.boric acid (B) treatments also significantly increased leaves carbohydrate, pigment and nutrients, i.e. N, P, K, Fe, Mn, Zn and B content, as well as carbohydrate, oil of flowers and its nutrients content as compared with the control. The results indicate that boron plays a very important role in increasing the seed yields through stimulating the physiological processes during reproductive growth phase of the plants (Misra andPatil, 2008).

Ge*et al*., (2006) investigated through a systematic study the effects of water stress on the activities of protective enzymes, lipid peroxidation and yield parameters of maize (Zea mays L.). Results showed that, under water stress, the activities of superoxide dimutase (SOD), catalase (CAT), and peroxidase (POD) inleaves and roots increased sharply with water stress. The content of melondialdehyde (MDA) increased by to the severity of water stress. The content of MAD in roots was lower than that in leaves. The content of soluble proteins in roots and leaves decreased with increasing drought stress. The economic yield of maize decreased significantly under water stress.

Conclusion

The physiological and biochemical changes that occur in maize crop subjected to water stress represent adaptive responses by which plants cope with the water deficit. Such species, growing under the low water content demonstrate an acclimation to this abiotic stress and are able to survive subsequent drought periods with less damage compared to other crops. Application of boron had increased soluble sugars, proteins, amino acid contents and dry mass in the stem ofmaize. Imposition of water stress significantly reduced the leaf ionic contents in contrast with boron foliar application which significantly increased them. Foliar spray showed non-significant effect on water relations parameters. On the basis of results it is concluded that B foliar spray at 100 ppm help to ameliorate water stress conditions.

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