Pak. J. Bot., 43(6): 2903-2910, 2011.

IMPACT OF BORON FERTILIZATION ON DRY MATTER PRODUCTION AND MINERAL CONSTITUTION OF IRRIGATED COTTON

NIAZ AHMED[1], MUHAMMAD ABID[1], FIAZ AHMAD[2], MUHAMMAD AMAN ULLAH[3], QAISAR JAVAID[4], AND MUHAMMAD ARIF ALI[1*]

[1]*University College of Agriculture, Bahauddin Zakariya University, Multan, Pakistan.*
[2]*Central Cotton Research Institute, 60500 Multan, Pakistan.*
[3]*Department of Statistics, Bahauddin Zakariya University Multan, Pakistan.*
[4]*Agricultural Chemist Soil & Water Testing Laboratory, Bahawalpur.*

Abstract

The inorganic fertilizers produce significant effects on quantity as well as quality on the produce of most of the crop plants: The productivity of cotton crop varies greatly due to addition of macro-and micro-nutrients. Among micro-nutrients, boron fertilizer holds significant importance in not only sustaining but also enhancing the yield of cotton. At the advent of excessive use of high analysis fertilizers, a wide spread deficiency of boron in soils of Pakistan is of common scene. However, research studies are limited on the quantity and the impact of boron fertilizer on production of biological yield and its chemical composition of cotton plant under irrigated conditions. The present study was therefore conducted to determine the influence of boron fertilizer on dry matter production and its interactive effects on other nutrients in plant system. The experiment was conducted on calcareous soils under irrigated conditions for two seasons 2004-2005 at Bahauddin Zakariya University, Multan. The treatments consisted of six levels of boron fertilizer i.e., 0.0, 1.0, 1.5, 2.0, 2.5 and 3.0 kg B ha^{-1} and were arranged in randomized complete block design with 4 replication. Cotton crop cv. CIM-473 was planted during the month of May and harvested in November each year. The standard production practices were followed. The results showed that application of boron fertilizer produced significant effect on enhancing biological yield of cotton. Maximum dry matter yield was achieved by addition of 3.0 kg B ha^{-1}. Crop planted during season 2005 produced higher quantity of biological yield compared to year 2004. The addition of various levels of boron caused substantial increase in the uptake of nitrogen, phosphorus, potassium, copper, iron, zinc and boron nutrients, while lowering down of calcium magnesium and manganese in different parts of the cotton plant. The enhanced assimilation of macro-nutrients resulted in greater production of biological yield and better growth and development of cotton plant.

Introduction

Cotton is a strategic crop to sustain economy of Pakistan. The country stands 4^{th} largest producer, 3^{rd} largest exporter, 4^{th} largest consumer of cotton in the world. Despite this fact, the productivity of cotton is far low compared to other cotton producing countries (Anon., 2007). The productivity of crop may be elevated by 50% by application of chemical fertilizers (Loneragan, 1997). Marschner (1995) reported that maintenance of optimal quantities of mineral constituents in the media and their uptake resulted in increased quantity and quality of the crop plants. However, assimilation of nutrients by different parts of plant is greatly influenced by various environmental factors. Drossopulos *et al*., (1994) reported that amount of mineral elements absorbed by a plant was a function of growth stages, genotypes, agronomic practices and environmental factors.

Deficiency of more than one nutrient is frequent in alkaline soils of Pakistan (Anon., 1998; Imtiaz *et al*., 2010). Fageria *et al*., (2002) reported that with the introduction of high yielding varieties, high cropping intensity and low or less use of organic manures caused widespread deficiencies of micronutrients. Boron deficiency is well established nutritional disorder of more than 100 crops in calcareous soils of more than 80 countries including Pakistan (Sillanpaa, 1982; Goldberg, 1997; Shorrocks, 1997; Rashid &Ryan, 2004; Rashid, 2006; Imtiaz *et al.*, 2010). Boron is an essential micro-nutrient for crop growth (Marschner 1995) as it is involved in various plant physiological and biochemical processes (Shelp, 1993; Blevins & Lukaszewski, 1998).

Supply of B in the substrate may affect the behavior of other nutrients in plants, but the specific function of B on the behavior of macro-and micro-nutrients is unclear (Bowen, 1981; Gomez-Rodriguez *et al*., 1981; Lopez-Lefebre *et al*., 2002). Most probably, because of its complex chemistry in soil. Therefore, a little information is known about its physiological and biochemical functions in plants. Its deficiency or excess may affect the solubility and availability of macro-and micro-nutrients in soil (Santra *et al*., 1989; Tariq & Mott, 2007; Ahmed *et al*., 2008). Therefore, the present study was conducted to evaluate the effects of soil applied B on dry-matter production and mineral constitution with relevance to boron concentration in different parts of cotton plant at maturity.

Materials and Methods

A permanent layout field experiment was conducted during crop seasons 2004 and 2005 at experimental farm of University College of Agriculture, Bahauddin Zakariya University, Multan, Pakistan (longitude: 71^o, 30.79’ E; latitude: 31^o, 16.4’; altitude: 128 m). The soil belongs to Sultanpur series (coarse silty, hyperthermic, Typic Haplocambid). The soil developed in an arid climate of sub-recent flood plains of the Indus delta. It is porous; friable, moderately calcareous, weakly structured (Anon., 1998). Composite soil samples (0-30 cm) collected prior to applying experimental treatments to cotton crop of 2004, were analyzed following procedures (Ryan *et al*., 2001). The soil was silt loam, non-saline (ECe, 1.8 dS m^{-1}), alkaline (pHs, 8.1), moderately calcareous ($CaCO_3$, 5.6%) and low in organic matter (0.78%). The soil contained $NaHCO_3$-extractable P (9 mg kg^{-1}); NH_4OAc-extractable K (102 mg kg^{-1}); DTPA-extractable Zn (0.54 mg kg^{-1}), and HCI-extractable-B (0.43 mg kg^{-1}) nutrients.

*Corresponding author: arif1056@hotmail.com

The treatments consisted of 6 levels of boron fertilizer i.e., 0.0, 1.0, 1.5, 2.0, 2.5 and 3.0 kg B ha^{-1} (as borax, 10.8% B). Treatments were arranged in a randomized complete block design with four replications. The seed of cotton variety CIM-473 was manually dibbled at a distance of 75 cm from row to row and 30 cm from plant to plant. The differential doses of boron fertilizer along with basal fertilizers of 50 kg N ha^{-1} (urea), 60 kg P ha^{-1} (triple superphosphate), 50 kg K ha^{-1} (sulphate of potash) and 5.0 kg. Zn ha^{-1} (zinc sulphate) were broadcast and incorporated in the soil. The remaining quantity of nitrogen was applied in two equal splits i.e., at flower initiation (60 days after planting) and peak flowering (75 days after planting) stages. The integrated weed and insect management was adopted to keep crop free from weeds and insect pests. The standard production practices were curried out to raise the crop.

At maturity, the plants were harvested from one square meter area from each treatment. The plants were partitioned into leaves, stems and bolls. The plant material was dried in an oven at 70±1°C for 48 h. The dried bolls were divided into burs, seed and lint. The biological yield was weighed to estimate the biomass production. The plant samples were ground and analyzed for nitrogen, phosphorus, calcium, magnesium, copper, iron, manganese and zinc according to methods (Ryan *et al*., 2001). For B determination, dried plant tissue samples were dry ashed for 6 hours at 600° C in a muffle furnace. The ash was dissolved in 0.36N H_2SO_4 (Gaines & Mitchell, 1979). The colour was developed by azomethane-H. Reading of the B was recorded on a spectrophotometer (PD303S) at 420 nm wave length (Bingham, 1982.)

The experimental data were analyzed statistically using "MSTAT C" (Anon., 1986). Least significant differences were used to differentiate significant treatment effects. The principal component analysis (PCA) was performed using Statistica software package (Statistica 8, Stat soft Inc. Tulsa OK, USA.).

Results

Dry matter production: Various treatments of boron fertilizer significantly ($p \leq 0.05$) affected dry matter yield (DMY) for both experimental years (Fig. 1). At given levels of B, the DMY was more during 2005 compared with 2004. Dry matter yield increased significantly with B upto 2.0 kg ha^{-1} and insignificant improvement occurred afterwards for both experimental years. Averaged across B treatments, there were 3.9, 11.5, 13.9, 15.2 and 16.3% increase for 2004 and 1.0, 8.4, 10.6 and 10.3% increase for 2005 in DMY with B from 1.0 to 3.0 kg ha^{-1} compared with control treatments. Averaged across cropping seasons, biological yield increased linearly with increasing of doses of boron fertilizer upto addition of 2.0 kg B ha^{-1}; however, response was flattened beyond this dose of fertilizer.

Ionic distribution: The various boron treatments significantly affected N concentration in leaves, stems, burs, seed and lint (Fig. 2A) for both experimental years. At given B levels, comparatively higher N concentration was observed in leaves, burs and seed for 2005 than 2004 crop. Averaged across B treatments, N varied in leaves form 1.89 to 1.94%, burs 0.55 to 0.58% and lint 0.10 to 0.12% for experimental years 2004 and 2005, respectively, whereas, it was almost similar in stems and seed for both experimental years (Fig. 2A). Maximum increase in N concentration was recorded in crop grown during 2005 compared to 2004. Nitrogen concentration was more in seed followed by leaves, stems, burs and lint with B fertilizer. Averaged across cropping seasons, nitrogen concentration increased with increasing levels of boron fertilizer. The application of 3.0 kg B ha^{-1} caused an increase of 12.7, 9.7, 12.5, 3.8 and 25.0% in leaves, stems, burs, seed and lint, respectively over untreated check.

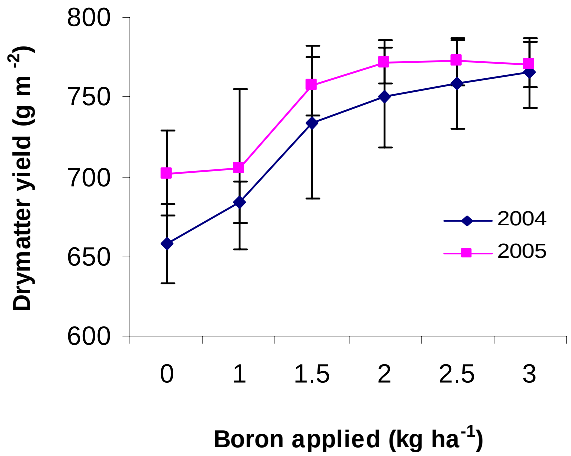


Fig. 1. Effect of soil applied boron on dry matter production. Verticle bars denote standard error.

Maximum increase in P concentration was 28.6 and 35.7% for leaves; 38.5 and 28.6% for burs; 29.4 and 33.3% for seeds with 3.0 kg B ha^{-1} compared with control treatment during 2004 and 2005, respectively. Among treatments, irrespective of cropping seasons, crop receiving 3.0 kg B ha^{-1} maintained the highest concentrations of P (i.e., 0.44, 0.19, 0.18, 0.07 and 0.06% in seed, leave, burs, stems and lint, respectively). The concentration of P in plant parts was in the order of seeds>leaves>burs>stems>lint (Fig. 2B).

Averaged across B treatments, maximum increase in K concentration was 23.1 and 26.8% for stems, 14.1 and 12.4% for burs, 10.0 and 9.24% for seeds, 33.3 and 26.7% for lint with 3.0 kg B ha^{-1} compared with control treatment during 2004 and 2005, respectively (Fig. 2C). Crop receiving 3.0 kg B ha^{-1} maintained highest concentration of K (i.e. 3.17, 2.16, 1.89, 1.23 and 0.90% in burs, leaves, seed, stems and lint, respectively).

There was a decrease in Ca concentration in leaves, stems, burs, seed and lint with addition of B levels for both experimental years (Fig. 2D). Decrease in Ca concentration was 11.8 and 9.9% for leaves; 16.6 and 16.0% for stems; 32.0 and 25.0% for burs; 44.0 and 37.0% for seed; 40.0 and 33.3% for lint with 3.0 kg B ha^{-1} compared with control plot for experimental years 2004 and 2005, respectively. It is also evident that irrespective of experimental years, crop treated with 3.0 kg B ha^{-1} had lowest concentration of Ca (i.e. 1.86, 0.45, 0.17, 0.14 and 0.03) for leaves, stems, burs, seed and lint, respectively. Calcium accumulation was in the order of leaves> stems>burs>seed>lint with B levels.

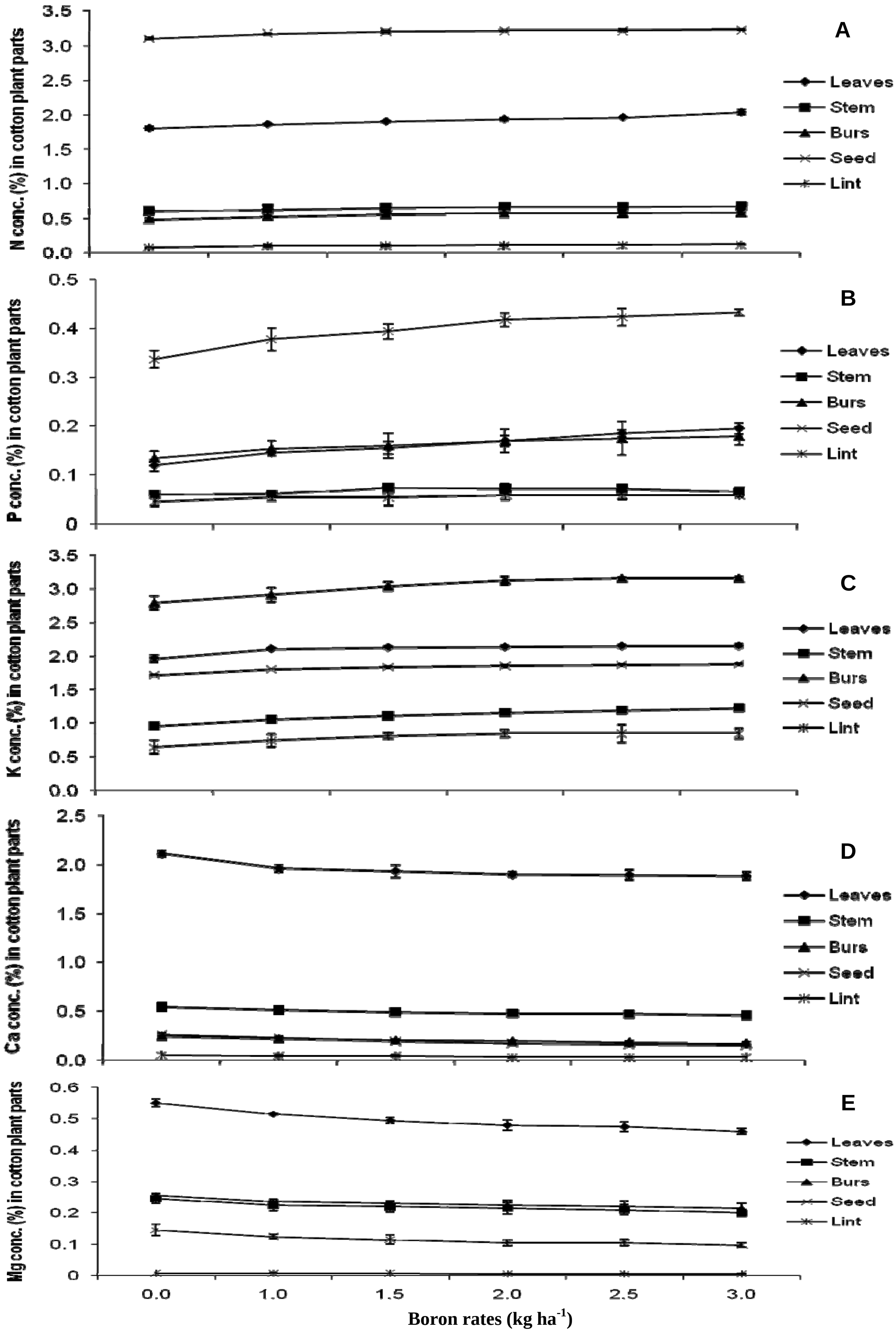


Fig. 2. Effect of soil applied boron on macronutrient conc. (%) in different cotton plant parts (Average of two seasons).

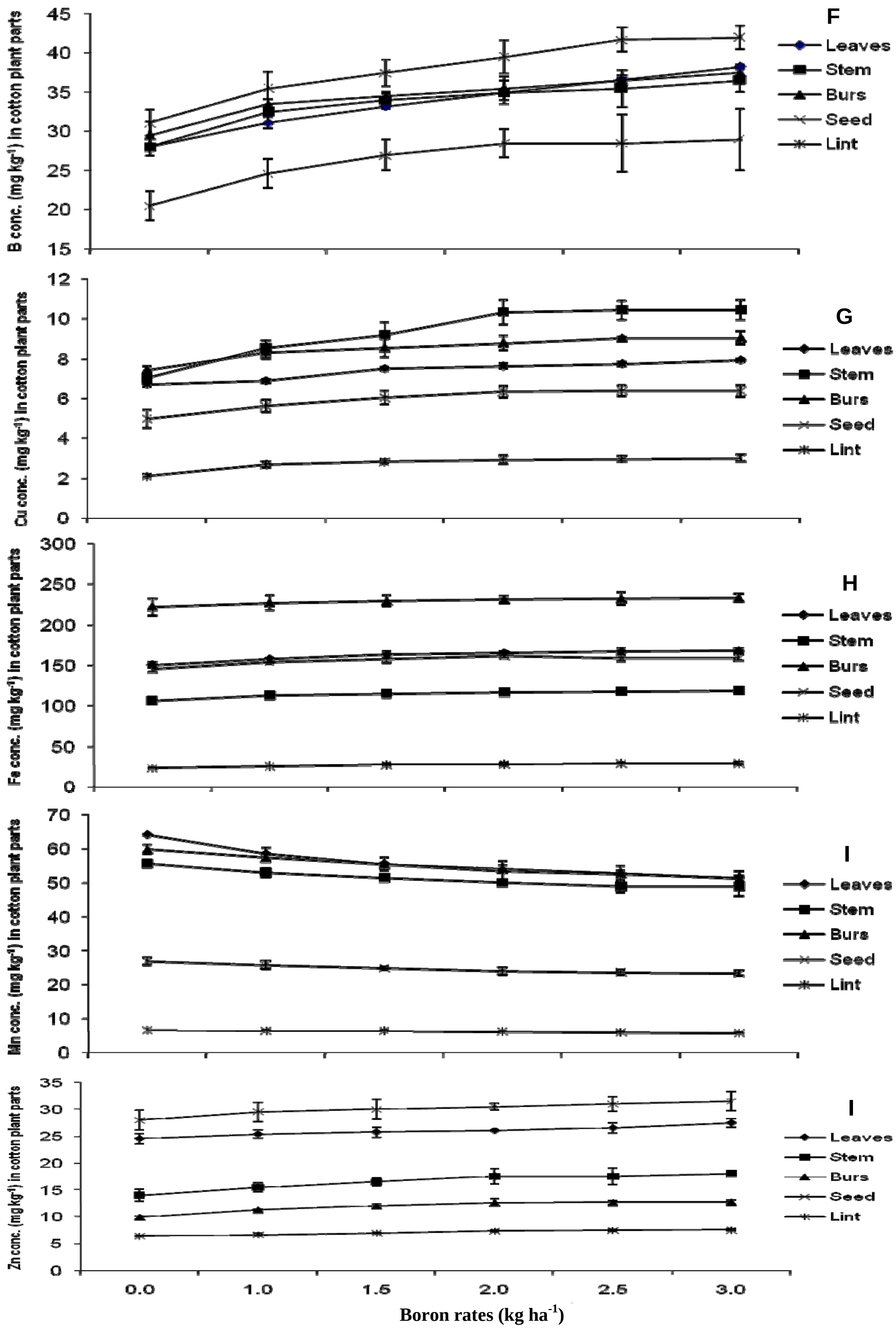


Fig. 3. Effect of soil applied boron on micronutrient conc. (mg kg^{-1}) in different cotton plant (Average of two seasons).

Boron treatments significantly lowered down Mg concentration in various plant parts upto application of 1.5 kg B ha^{-1}; thereafter it remained constant from 1.5 to 3.0 kg B ha^{-1} for experimental years 2004 and 2005(Fig. 2E). Averaged across seasons, maximum decrease in Mg concentration was 8.1, 16.3, 16.2, 23.0 and 33.3 in leaves, stems, burs, seed and lint, respectively by addition of 3.0 kg B ha^{-1}. Cotton crop grown during 2004 maintained 11.1, 5.7, 14.4, 8.8 and 14.3% higher content of B compared to control plots during crops 2004 and 2005, respectively. Averaged across crop seasons, concentration of B in leaves, stems, burs, seed and lint varied from 32.9 to 34.4, 32.8 to 34.2, 33.9 to 35.0, 37.5 to 38.2 and 25.8 to 26.8 mg kg^{-1}, respectively in different treatments (Fig. 3F).

Cotton crop for the year 2005 absorbed higher concentration of Cu compared to year 2004. Averaged across seasons, concentration of Cu increased linearly with increase in levels of boron fertilizer. The crop treated with 3.0 kg B ha^{-1} absorbed higher quantity of 10.8, 21.2, 14.0, 28.0, 42.9% in leaves, stems, burs, seed and lint at 3.0 kg B ha^{-1} compared to untreated check, respectively(Fig. 3G).

Crop for the year 2005 absorbed higher quantity of Fe by 2.26, 6.44, 15.9, 3.43 and 1.7% compared to year 2004. Averaged across seasons, Fe content increased significantly with increasing levels of boron fertilizer. Crop treated with 3.0 kg B ha^{-1} absorbed higher quantity of Fe by 11.5, 10.1, 3.5, 7.8 and 23.3% compared to untreated check, respectively (Fig. 3H).

Data for manganese content differed significantly due to cropping seasons and various levels of boron fertilizer. Crop grown during 2005 maintained higher quantity of Mn by 8.4, 4.1, 3.2, 4.5, 2.9% in leaves, stems, burs, seed and lint, respectively compared to year 2004. The addition of boron fertilizer significantly lowered down Mn content in various plant parts. The reduction in Mn content was 12.7, 8.3, 7.9, 7.9 and 5.3% in leaves, stems, burs, seeds and lint over the control, respectively by addition of 3.0 kg B ha^{-1} (Fig. 3I).

Data for zinc content differed significantly due to cropping seasons and various rates of boron fertilizer. Crop planted during 2005 absorbed higher quantity of Zn in most of the cases compared to season 2004. The addition of boron fertilizer caused increase in Zn content linearly with increasing doses of boron fertilizer. The crop treated with 3.0 kg B ha^{-1} maintained higher quantity of 5.7, 14.3, 19.6, 7.1 and 17.1% in leaves, stems, burs, seed and lint over untreated check, respectively (Fig. 3J).

Principal component analysis (PCA): PCA of various nutrient concentrations were performed to show the correlation between concentrations of different nutrients. The ordination of first two axes (axis 1 and axis 2) for the nutrient concentrations in leaves, stem, burs, seeds and lint of cotton crop explained 79.92, 71.36, 74.4, 78.12 and 68.67% correlation, respectively (Fig. 4). PCA ordination also indicates that most of the eigenvectors are aligned along the axis 1, hence maximum of the correlation values are explained by axis 1 and a very low percentage of correlation is explained by axis 2. It is also obvious from PCA ordination (Fig. 4) that B is positively correlated with N, P, K, Zn, and Cu and negatively correlated with Ca, Mg, and Mn in leaves, stem, burs, seeds and lint.

Discussion

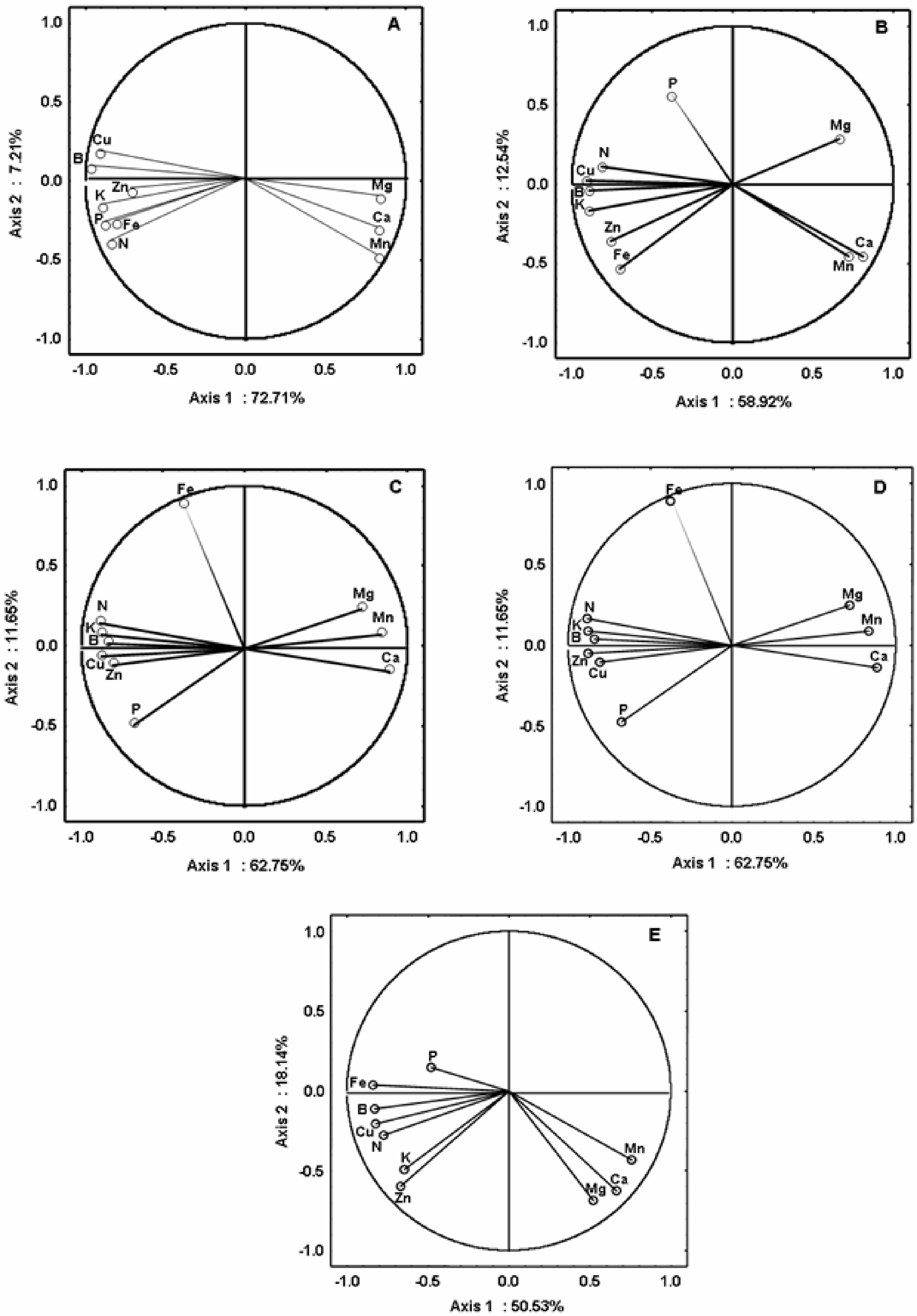
The results regarding increase in DMY are similar with those of Malik *et al*., (1992); Rosolem & Costa (2000); Zhao & Oosterhuis (2003); Fontes *et al*., (2008) who reported that B application increased DMY of cotton. Similarly Lopez-Lefebre *et al*., (2002) reported also that application of B along with NPK fertilizers increased dry matter yield of tobacco (*Nicotiana tabacum* L.). Shelp (1993) and Ruiz *et al*., (1998) reported that increase in DMY could be due to activation of some of the fundamental processes with B nutrient such as cell elongation and division as well as nucleic acid metabolism. Qiong *et al*., (2002) reported that B fertilizer significantly enhanced photosynthetic activity of leaves, which consequently resulted in more accumulation of dry matter in peanut (*Arachis hypogia* L.).

Boron interactions either synergism or antagonism could affect plant nutrition of both deficient and toxic conditions. Therefore, differences and contradictions in plant nutrient absorption regarding B fertilizer have been reported. These could be due to different growth media, crop species and varieties, plant parts analyzed, plant age, and environmental conditions (Tariq & Mott, 2007).

Data of current study show that N concentration increased with increasing levels of B fertilizer. These results are similar with those of Singh & Singh (1983, 1984), who reported positive correlation between B and N in leaves. Similarly, Lopez-Lefebre *et al*., (2002) also reported positive correlation between B and N in leave. Similarly, Lopez-Lefebre *et al*., (2002) reported the effects of B on N metabolism due to (a) a positive influence on enzymatic protein synthesis, (b) indirectly by promoting the entrance of substrate through plasma membrane to the interior of the cells.

Assimilation of P was appreciably enhanced with B supply. There was a positive and significant correlation between B and P in leaves, burs, seed and lint (whereas, non-significant correlation with P in stems), which indicated that B fertilizer improved P use efficiency in cotton plant. Various researchers (Pollard *et al*., 1977; Lopez-Lefebre *et al*., 2002; Chatterjee *et al*., 1990) observed also similar results that supply of B fertilizer significantly increased P content in different plant parts. Lopez-Lefebre *et al*., (2002) reported 23 and 15% increase in P concentration in roots and leaves of tobacco (*Nicotiana tabacum* L.) with 20 µM boric acid in solution culture compared with control. A positive correlation between B and K contents of 98 grasses at flowering stage was also observed by Tolgyesi and Kozma (1974).

Application of B gradually increased K concentration in chickpea and wheat on sandy soil (Yadava & Manchanda, 1979). These results are in accord to that of various researches (Yadav & Manchanda, 1979; Francois 1984; Pal *et al.*, 1989) for gram and wheat, tomato and berseem, respectively. Our results show the antagnostic relationship between B and Ca in different plant parts. Relationships between B and Ca contents were found negatively in 98 grasses at the flowering stage (Tolgyesi & Kozma, 1974). The decrease in Ca concentration with increasing B in lentil (*Lenus culinaris* Medic.) and barley was also reported by Singh & Singh (1983, 1984). Miller & Smith (1977) also observed similar results that Ca concentration decreased in upper and lower leaves and stems of alfalfa (*Medicago sativa* L.) with B levels. Muhiling *et al*., (1998) and Sotiropoulos *et al*., (2002) also suggested antagonistic relationship between B and Ca for bean (*Vicia faba*) and kiwi fruit (*Actinidia deliciosa*), respectively. Cramer *et al*. (1991) reported that there could be a competition between cations uptake in barley plant.



A= Leaves, B= Stem, C= Bur, D= Seed, E= Lint

Fig. 4. PCA ordination of various nutrient concentrations in leaves, stems, burs, seeds and lint of cotton crop.

There was decrease in Mg concentration with B rates in different plant parts. The results agree with those of Cramer *et al*., (1991) and Lopez-Lefebre *et al.*, (2002) who reported a negative correlation between B and Mg in leaves, stems, burs, and seed. This might be due to competition between cations such as K and Mg at root level.

There was a positive effect of B rates on B, Cu, Fe, and Zn in different plant parts; whereas Mn concentration decreased. These results are similar with those of El-Gharably & Bussler (1985), who reported that B concentration was higher by 322, 383 and 447% in roots, young and old leaves, respectively with 50 ppm B in solution culture. Zhao & Oosterhuis (2002) reported significant differences in B concentrations in leaf blades, petioles and fruits of cotton plant with 2.2 kg B ha^{-1} compared to untreated check. They further reported that among the four plant tissues (leaf blades, stems, petioles, and fruits), leaf blades had the highest and stems had the lowest B concentration with 2.2 kg B ha^{-1}. Miller & Smith (1977) reported that B concentration for alfalfa was 78 and 122 mg kg^{-1} in lower leaves and 62 and 86 mg kg^{-1} in upper leaves; whereas 17 and 21 mg kg^{-1} in lower stems and 23 and 28 mg kg^{-1} in upper stems with control and 12.5 kg B ha^{-1} treatments, respectively. Further, they concluded that leaves contained more B than stems, while lower leaves maintained more B than that of upper ones. Similarly, El-Gharably & Bussler (1985) reported that there were 24, 40 and 221% increase in Cu concentration for roots, young leaves and older leaves with 50 ppm B in a solution culture compared with control treatment, respectively. Under B deficient conditions, concentration of Cu decreased in tomato leaf (Carpena-Artes & Carpena-Ruiz, 1987). Alvarez-Tinaut (1990) found positive correlation between B and Fe and Cu contents of sunflower. They suggested that B could indirectly affect catalase activity via Fe and Cu. However, Ohki (1975) reported that concentration of Cu remained unaffected in blades of cotton at lower and higher levels of B. Application of B at higher rates depressed the concentrations of Mn in most of crops (Leece, 1978). Santra *et al*., (1989) reported antagonistic relationship between B and Mn in rice. Data reported herein indicate an increase in Fe and Zn concentration accrued in leaves, stems, burs, seed and lint with increasing B rates. Patel & Golakiya (1986) reported that uptake of Fe was increased with B application in groundnut. Under B deficient conditions, Fe decresed in tomato leaves; whereas increased the Fe concentration (Carpena-Artes & carpena-Ruiz, 1987). Zinc concentration in wheat shoots enhanced with foliar application of B (Shaaban *et al*., 2004). Zinc deficiency increased B accumulation (Graham *et al*., 1987), whereas its application diminished B accumulation and toxicity on plants grown in soils containing higher concentration of B (Moraghan & Mascagni, 1991; Swietlik, 1995).

Conclusions

Crop planted during crop season 2005 produced higher quantity of biological yield compared to crop season 2004. The availability of sufficient quantity of boron nutrient in the medium resulted in greater uptake of macro-nutrients by cotton crop. The application of boron fertilizer caused increase in the accumulation of nitrogen, phosphorus, potassium, copper, iron, zinc and boron, while reduction in calcium, magnesium and manganese concentration in different parts of the cotton plant.

Acknowledgments

Financial support for the study was provided by the Higher Education Commission of Pakistan is gratefully acknowledged.

References

Ahmed, N., M. Abid and F. Ahmad. 2008. Boron toxicity in irrigated cotton (*Gossypium hirsutum* L.). *Pak J. Bot*., 40: 2442-2452.

Alvarez-Tinaut, M.C. 1990. Correlations between boron and other micronutrients. In: *Behavior, Function and Significance of Boron in Agriculture*. Report on an International Workshop at St. John's College, Oxford, England. 23-25 July, 1990. Published by Borax Consolidated Limited, London. SW 1P 1H T, UK.

Anonymous. 1986. User's guide: A microcomputer program for the design management and analysis of agronomic research experiments. Michigan State Univ., East Lansing, MI, USA.

Anonymous. 1998. *Micronutrients* in agriculture. Pakistan perspective. National Fertilizer Development Center, Islamabad, Pakistan. p. 1-51.

Bingham, F.T. 1982. Boron. p. 431-448. In: *Methods of Soil Analysis*. (Ed.): A.L. Page. Part II; Chemical and Microbiological Properties. Am. Soc. Agron. Madison, WI, USA.

Blevins, D.G. and K.M. Lukaszewski. 1998. Boron in plant structure and function. *Annu. Rev. Plant Physiol. Plant Mol. Bio*., 49: 481-500.

Bowen, J.E. 1981. Micro-element nutrition of sugarcane. I. Interaction in microelements accumulation. *Trop. Agric*., 58: 215-220.

Carpena-Artes, O. and R.O. Carpena-Ruiz. 1987. Effects of boron in tomato plant leaf. evaluations. *Agrochimica*, 31: 391-400.

Chatterjee, C., P. Sinha and S.C. Agarwala. 1990. Interactive effect of boron and phosphorus on growth and metabolism of maize grown in refined sand. *Can. J. Plant Sci*., 70: 455-460.

Cramer, G.R., E. Epstein and A. Lauchi. 1991. Effects of sodium, potassium and calcium on salt –stressed Barley. ll. Elemental analysis. *Physiol. Plant*., 81: 197-202.

Drossopoulos, J.B., D.L. Bouranis and B.D. Bairakatari. 1994. Patterns of mineral fluctuations in soybean leaves in relation to their position. *J. Plant Nutr*., 17: 1017-1035.

El-Gharably, G.A. and W. Bussler. 1985. Critical levels of boron in cotton plants. *Z. Planzen. Bodenk*., 148: 681-688.

Fageria, N.K., V.C. Baligar and R.B. Clark. 2002. Micronutrients in crop production. *Adv. Agron.,* 77: 185-268.

Fontes, R.L.F. J.F. Medeiros, J.C.L. Neves, O.S. Carvalho and J.C. Medeiros. 2008. Growth of Brazilian cotton cultivars in response to soil applied boron. *J. Plant Nutr*., 31: 902-918.

Francois, L.E.1984. Effect of excess boron on tomato yield, fruit size and vegetative growth. *J. Am. Soc. Hort. Sci*., 109: 322-324.

Gaines, T.P. and G.A. Mitchell. 1979. Boron determination in plant tissue by the azomethine-H method. *Commun. Soil. Sci. Plant Anal.*, 10: 1099-1108.

Goldberg, S. 1997. Reactions of boron with soils. *Plant Soil,* 193:35-48.

Gomez-Rodriguez, M.V., M. Gomez-Ortega and M.C. Alvarez-Tinaut. 1981. Boron, copper iron, manganese and zinc contents in leaves of flowering sunflower plants (*Helianthus annus* L.) grown with different boron supplies. *Plant Soil*. 62: 306-316.

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

Anonymous. 2007. Supply and distribution of cotton. Newsletter. International Cotton Advisory Committee. December 3, 2007.Washington, DC 20006, USA.

Imtiaz, M., A. Rashid, P. Khan, M.Y. Memon and M. Aslam. 2010 The role of micronutrients in crop production and human health. *Pak. J. Bot*., 42: 2565-2578.

Leece, D.R. 1978. Effects of boron on the physiological activity of zinc in maize. *Aust. J. Agric. Res*., 29: 739-749.

Loneragan, J.F. 1997. Plant nutrition in the 20th and perspective for the 21st century. *Plant Soil*, 196: 163-174.

Lopez-Lefebre, L.R., R.M. Rivero, P.C. Garcia, E. Sanchez, J.M. Ruiz and L. Romero. 2002. Boron effect on mineral nutrients of tobacco. *J. Plant Nutr*., 25: 509-522.

Malik, M.N.A., M.I. Makhdum and S.I.H. Shah. 1992. Cotton response to boron fertilizer in silt loam soils. p. 331-336. In: *Soil health for sustainable agriculture*. Proc. 3rd National Cong. Soil Sci. March 20-22, 1990. Soil Sci. Soc. Pak., Lahore, Pakistan.

Marschner, H. 1995. *Mineral Nutrition of Higher Plants*. 2nd ed. Academic Press, London, UK.

Miller, R.D. and R.K. Smith. 1977. Influence of boron on other chemical elements in alfalfa. *Commun. Soil Sci. Plant Anal*., 8: 465-478.

Moraghan, J.T. and H.J. Mascagni, Jr. 1991. Environmental and soil factors affecting micronutrient deficiencies and toxicities. p. 371-425 In: Mortvedt *et al*. (eds.) *Micronutrients in agriculture*, 2nd Soil Sci. Soc. Am., Madison, WI, USA.

Muhling, K.H., M. Wimmer and H.E. Goldbach. 1998. Apoplastic and memrane-associated Ca^{+2} in leaves and roots as affected by boron deficiency. *Physiol. Plant*., 102: 179-184.

Ohki, K. 1975. Mn and B effect on micronutrients and P in cotton. *Agron. J*., 67: 204-207.

Pal, B., S.P.S. Jadaun and C.S. Raghav. 1989. Effect of phosphorus and boron application on dry matter yield and nutrient contents in berseem. *J. Indian Soc. Soil Sci.* 37: 579-581

Patel, M.S. and B.A. Golakiya. 1986. Effect of calcium carbonate and boron application on yield and nutrient uptake by groundnut. *J. Indian Soc. Soil Sci*., 34: 815-820.

Pollard, A.S., A.J. Parr and B.C. Loughman. 1977. Boron in relation to membrane function in higher plants. *J. Exp. Bot*., 28:831–841.

Qiong, D.Y.L. X. Rong, H.J. Hua, H. Zhiyao and Z.X. Hong, 2002. Effect of boron and molybdenum on the growth development and yield of peanut. *Plant Nutri. Fert. Sci*.,8:2, 233.

Rashid, A. 2006. Boron deficiency in soils and crops of Pakistan: Diagnosis and Management.PARC, Islamabad, Pakistan

Rashid, A. and J. Ryan. 2004. Micronutrient Constraints to Crop production in soils with Mediterranean type characteristics: A Review. *J. Plant Nutr*., 27: 959-975.

Rosolem, C.A. and A. Costa. 2000. Cotton growth and boron distribution in the plant as affected by a temporary deficiency of boron. *J. Plant Nutr*., 23: 518-825.

Ruiz, J.M., M. Baghour, G. Bretones, A. Belakir and L. Romero. 1998. Nitrogen metabolism in tobacco plants (*Nicotiana tabacum* L.): Role of boron as a possible regulatory factor. Int. *J. Plant Sci*., 159: 121-126.

Ryan, J., G. Estefan and A. Rashid. 2001. *Soil and plant analysis laboratory manual.* 2nd ed. Int. Center for Agric. Res. in the Dry Areas(ICARDA), Allepo,Syria.

Santra, G.H., D.K. Das and B.K. Mandal. 1989. Relationship of boron with iron, manganese, copper and zinc with respect to their availability in rice soil. *Environ. Ecol*., 7: 874-877.

Shaaban, M.M., M. Fouly and A.A. Abdel-Maguid. 2004. Zinc boron relationship in wheat plants grown under low of high levels of calcium carbonate in the soil. *Pak. J. Biol. Sci*., 7: 633-639.

Shelp, B.J. 1993. Physiology and biochemistry of boron in plants. p. 53-85. In: Gupta, U.C. (ed.), *Boron and its Role in Crop Production*. CRC Press, Boca Raton, FL, USA.

Shorrocks, V.M. 1997. The occurrence and correction of boron deficiency. *Plant Soil* 193: 121-148.

Shorrocks, V.M. 1992. Boron-Recent development and some views on its role in plants. p. 78-80 In: Portch, S. (ed.). *Proc. Int. Symp. on the role of sulphur, magnesium and micronutrients in balanced Plant Nutrition*. The Sulphur Institute, Washington, DC, USA.

Sillanpaa, M. 1982. *Micronutrients and the nutrient status of soils*: A global Study. FAO Soil Bull. No. 48. Food and Agriculture Organization, Rome, Italy.

Singh, V. and S.P. Singh. 1983. Effect of applied boron on the chemical composition of lentil plants. *J. Indian Soc. Soil Sci*., 31: 169-170.

Singh, V. and S.P. Singh. 1984. Effect of applied boron on nutrients and uptake by barley crop. *Curr. Agric*., 8: 86-90.

Soil Survey Staff. 1998. *Keys to Soil taxonomy*. 8th Ed. United States Department of Agriculture, National Sources Conservation Service: Washington, DC, USA.

Sotiropoulos, T.E., N.I. Therios, N.K. Dimassi, A. Bosbalidis and G. Kofilids. 2002. Nutritional status, growth, CO_2 assimilation, and leaf anatomical responses in two kiwi fruit species under boron toxicity. *J. Plant Nutr*., 5: 1244-1261.

Swietlik, D. 1995. Interaction between zinc deficiency and boron toxicity on growth and mineral composition of sour orange seedlings. *J. Plant Nutr*., 18: 1191-1207.

Tariq, M. and C.J.B. Mott. 2007. Effect of boron on the behaviour of nutrients in soil –plant systems-A review. *Asian J. Plant Sci*., 6: 195-202.

Tolgyesi, G. and A. Kozma. 1974. Investigation on factors affecting boron uptake by grasses. *Agrokemia-es-Talajatan*, 23: 83-98

Yadav, O.P. and H.R. Manchanda. 1979. Boron tolerance studies in gram and wheat grown on a sierozem sandy soil. *J. Indian Soc. Soil Sci*., 27: 174-180.

Zhao, D. and D.M. Oosterhuis. 2002. Cotton carbon exchange, nonstructural carbohydrates, and boron distribution in tissues during development of boron deficiency. *Field Crops Res*., 78: 75-87.

Zhao, D. and D.M. Oosterhuis. 2003. Cotton growth and physiological responses to boron deficiency. *J. Plant Nutr.*, 26: 855-867.

(Received for publication 30 December 2010)