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Effect of K, Zn and B levels on their concentration, uptake, yield, potassium use efficiency and partial factor productivity in wheat in an acid Alfisol

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Abstract

The present investigation was carried out at experimental farm of Department of Soil Science, College of Agriculture, CSK HPKV, Palampur with sixteen treatments consisting of four levels of K (0, 50,100 and 150% of recommended dose), two levels of Zn (0 and 10 kg ha^{-1}) and two levels of B (0 and 1 kg ha^{-1}) . Highest grain (42.52q ha^{-1}) and straw (66.80 q ha^{-1}) yield of wheat was recorded under 150 per cent of recommended dose of wheat. Application of 150 per cent of recommended dose of K increased grain and straw yield by 43.7 and 46.9 per cent over no K, respectively. Application of Zn (10 kg ha^{-1}) increased grain and straw yield by 10.9 and 9.8 per cent over no Zn, respectively. The increase in grain and straw yield with the application of B (1 kg ha^{-1}) was 5.6 and 6.3 per cent, respectively. Application of K increased K, Zn and B contents significantly at maximum tillering and harvesting. Application of Zn increased Zn and B contents significantly at both the stages. However, B increased the contents of Zn and B only at maximum tillering stage and at harvesting (grain and straw). Almost similar effects of K, Zn and B application on total nutrient uptake were observed. Application of Zn increased partial factor productivity, physiological efficiency, agronomic efficiency and apparent recovery. Boron application increased partial factor productivity and apparent recovery only.

Key words: Potassium, zinc, boron, wheat yield, uptake, potassium use efficiency, Alfisol.

Continuous heavy application of only one nutrient disturbs the nutrient balance and leads to depletion of other nutrients as well as the under-utilisation of nutrients supplied through fertilizers. Single nutrient approach has often caused reduced fertilizer use efficiency and consequent problems of multiple nutrients deficiencies in intensive cropping systems. Accelerated depletion of micronutrients from soil due to enhanced food grain production has accentuated the micronutrients deficiencies in many parts of India, which has brought sharp reduction in the macronutrient (NPK) use efficiencies (Shukla *et al.* 2009). Secondly, interactions among nutrients are also important as the supply of one nutrient affects the absorption, distribution or function of another nutrient. Identification and exploitation of positive interactions hold the key for increasing returns in terms of yield, quality and nutrient use efficiency.

With increasing cost of fertilizers farmers often skip or use limited quantity of potassic fertilizers. Consequently, mining of native soil potassium is increasing at an alarming rate (Sharma *et al.* 2001). As a result of these increasing incidences of potassium deficiencies being observed in different crops in the state, there is need for better understanding of potassium fertilization in agriculture. Since we are meeting the major K need of the crops by importing potassic fertilizers totally from other countries there is a need to improve potassium use efficiency

Apart from potassium, deficiencies of zinc and boron are also increasing (Singh 2009). Occurance of multiple mineral deficiencies reduces nutrient use efficiency drastically. The information on effect of zinc and boron on potassium use efficiency is not available in wheat crop in the region hence the investigation was undertaken.

Materials and Methods

The present investigation was undertaken with sixteen treatment combinations of four levels of potassium (0, 50,100 and 150 % of recommended dose of K), two levels of zinc (0 and 10 kg ha $^{-1}$) and two levels of boron (0 and 1kg ha $^{-1}$) in factorial randomized block design. The treatments were replicated three times. The field experiment was conducted on wheat crop (HPW155) under irrigated conditions at experimental farm of Department of Soil Science, CSK HPKV, Palampur during *rabi* 2010-11. The experimental farm is situated at 32°6′ N latitude and 76°3′ E longitude at an altitude of about 1290 m above mean sea level and lies in the Palam valley of Kangra district at the foothills of Dhauladhar ranges. The area is characterized by wet temperate climate having severe winters and mild summers with mean annual temperature ranging from around 10 °C in January to 30°C during May and June. The average annual rainfall ranges between 1500 to 3000 mm, out of which about 80 per cent is received during monsoon period (June to September).

The soil of experimental site was acidic with pH value of 5.3 and was classified as "*Typic Hapludalf*". The experimental soil was silty clay loam in texture, medium in organic carbon, available N, P and K. The contents of DTPA extractable Fe, Mn and Cu were adequate whereas DTPA extractable Zn and hot water soluble B were marginal, content being 0.63 and 0.88 mg kg $^{-1}$, respectively. Recommended dose of N, P_2O_5, K_2O for wheat is 120, 60, 30 kg N, respectively. Half dose of N and full dose of P and different doses of K, B and Zn were applied as per treatments at the time of sowing of the crop. The remaining half N was top dressed at 30 DAS. The sources of N, P, K, Zn and B were urea, single superphosphate, muriate of potash, zinc oxide and borax, respectively. The wheat crop (HPW 155) was sown on 29th November, 2010 and harvested on 30th May, 2011. The crop was grown with recommended package of practices under irrigated conditions.

Plant samples were collected at maximum tillering stage. Grain and straw samples were collected at the harvest of the crop. The samples were washed with distilled water. The dried samples were ground with steel grinder to pass through 1 mm sieve and stored in paper bags for subsequent analysis. Potassium concentration in grain and stover was determined by the method as described by Jackson (1967). The plant zinc concentration was determined after digesting plant samples with diacid mixture of nitric and perchloric acid in 9:4 ratio suggested by (Jackson, 1967) using atomic absorption spectrophotometer. Plant boron concentration was determined by Carmine method (Hatcher and Willcox, 1954). The uptake of each nutrient was calculated by multiplying the per cent concentration of the nutrient in the grain and straw with grain and straw yield of the crop, respectively. The uptake of the nutrient obtained in respect of grain and straw was summed up in order to compute the total nutrient uptake by the crop. The different indices of potassium use efficiency were calculated as per the formulae reported by Surekha *et al.* (2003). Following formulae were used:

a. Agronomic Efficiency (kg grain/ kg K applied) =

$$\frac{\text{Grain yield in fertilized plot} - \text{Grain yield in unfertilized plot}}{\text{Quantity of total fertilizer of K applied}}$$

b. Physiological Efficiency (kg grain/ kg K uptake) =

$$\frac{\text{Grain yield in fertilized plot} - \text{Grain yield in unfertilized plot}}{\text{K uptake in fertilized plot} - \text{K uptake in unfertilized plot}}$$

c. Apparent Recovery (%) =

$$\frac{\text{(Uptake of K in fertilized plot} - \text{uptake of K in unfertilized plot}}{\text{Quantity of total fertilizer K applied}} \times 100$$

d. Partial Factor Productivity (kg grain/ kg K applied) =

$$\frac{\text{Wheat grain yield in fertilized plot (kg ha}^{-1})}{\text{Quantity of fertilizer applied (kg K ha}^{-1})}$$

Results and Discussion

Crop productivity

Graded levels of K increased grain and straw yield of wheat significantly. Compared to 29.59 under no K, application of 50, 100 and 150 per cent of recommended dose of K recorded 34.91, 39.57 and 42.52 q ha^{-1} grain yield, respectively (Table 1). As such, application of 50,100 and 150 per cent of recommended dose of K registered increase in the grain yield to the order of 18, 33.7 and 43.7 per cent, respectively, over no application. Similar to grain yield, straw yield was also influenced significantly with the application of potassium. The increased yield might be due to increased availability, absorption and translocation of K (Yadav *et al.* 2012). Mishra (2003), Yadav and Yadav (2004) and Raghav *et al.* (2011) also observed the significant effect of K application on crop yield at different locations.

Similar to K, application of Zn @ 10 kg ha^{-1} resulted in significant increase in grain and straw yield of wheat. Application of Zn @ 10 kg ha^{-1} recorded grain yield of 38.55 q ha^{-1} compared to 34.75 q ha^{-1} under Zn_0 treatment. As such, there was an increase to the extent of 10.9 per cent with the application of Zn over no application. Like grain yield, straw yield also recorded significant increase with the use of Zn. Since growth and yield attributes of wheat under present study were enhanced significantly with the application of Zn, the sum total of these effects might have led to increase in crop yield due to zinc application. This might be due to its function as catalyst or stimulant in most of the physiological and metabolic processes and metal activator of enzymes helping in carbohydrate and protein synthesis. Such physiological and biochemical processes might have resulted in increased growth and development of plant which ultimately gave higher grain and straw yield of wheat. These findings are in accordance with those reported by Shaheen *et al.* (2007) and Abbas *et al.* (2009) in wheat.

Irrespective of K and Zn levels, application of B exhibited significant positive influence on grain and straw yield of wheat. The grain yield recorded under B_1 and B_0 was 35.64 and 37.65 q ha $^{-1}$, respectively. The results demonstrated that, in general, the extent of increase in crop yield was comparatively higher with the application of zinc when compared to B. The increase in crop yield of wheat may be ascribed to positive influence of boron on physiological processes involved in plant growth and maturation (Hossain *et al.* 2002). As positive influence of B was observed in case of growth and yield attributes of wheat, the increase in wheat yield with the application of B is obvious.

Nutrient concentration in wheat

At maximum tillering stage

Potassium

Application of potassium had significant effect on potassium concentration. Each successive increment in K levels resulted in significant increase over the preceding level. Application of K_0, K_{50}, K_{100} and K_{150} recorded 1.26, 1.38, 1.47 and 1.55 per cent K, respectively (Table 2). The increase in K concentration at maximum tillering stage might be due to higher availability of K to growing plants because of external application of K. These results are in accordance with the findings of Yadav *et al.* (2012). Potassium concentration increased significantly with the application of Zn and was 1.52 per cent at Zn_{10} and 1.31 per cent at Zn_0. Application of boron significantly influenced the K concentration in wheat at maximum tillering and values varied from 1.39 per cent under B_0 to 1.45 per cent in B_1, respectively. Potassium content increased with increasing level of boron because the latter depresses the uptake of Ca which might have antagonistic effect on K.

Zinc

Application of potassium resulted in decreased zinc content. Zn content decreased from 27.67 mg kg^{-1} under K_0 to 23.33 mg kg^{-1} under $K_{150.}$ However, zinc contents at K_0 and K_{50} were statistically at par. This might be due to the antagonistic effect of K on Zn content.

Application of zinc @ 10 kg ha^{-1} recorded zinc content of 29.29 mg kg^{-1} which was significantly higher than no zinc application (22.33 mg kg^{-1}). The increase in Zn content with the application of Zn may be attributed to its enhanced supply through zinc oxide added . Similar to Zn application, addition of B enhanced the zinc concentration significantly. It varied from 25.00 mg kg^{-1} in B_0 to 26.63 mg kg^{-1}under B_1.

Boron

Application of 50, 100 and 150 per cent of recommended dose of K recorded 16.08, 18.05 and 21.33 mg kg^{-1} B, respectively against 13.31 mg kg^{-1} in case of no K application (Table 2). This may be due to the synergistic relationship between potassium and boron (Ujwalaranade Malvi, 2011). Application of zinc enhanced boron content at maximum tillering significantly from 16.96 mg kg^{-1}(Zn_0) to 17.42 mg kg^{-1}(Zn_{10}). Application of boron enhanced the boron content significantly at maximum tillering stage. The increase in boron

Table 1. Effect of potassium, zinc and boron on grain and straw yield (q ha^{-1})

Treatment	Grain	Straw
K level (% of recommended)		
K_0	29.59	45.47
K_{50}	34.91	50.25
K_{100}	39.57	59.95
K_{150}	42.52	66.80
CD (P=0.05)	2.51	3.04
Zn level (kg ha^{-1})		
Zn_0	34.75	53.03
Zn_{10}	38.55	58.21
CD (P=0.05)	1.78	2.15
B level (kg ha^{-1})		
B_0	35.64	53.93
B_1	37.65	57.31
CD (P=0.05)	1.78	2.15

Table 2. Effect of potassium, zinc and boron on K, Zn and B content in grain and straw after harvest

Treatment	K (%)			Zn (mg kg^{-1})			B (mg kg^{-1})		
	At maximum tillering	At Harvest		At maximum tillering	At Harvest		At maximum tillering	At Harvest	
		Grain	Straw		Grain	Straw		Grain	Straw
K level (% of recommended)									
K_0	1.26	0.31	0.55	27.67	20.08	17.25	13.31	5.37	9.21
K_{50}	1.38	0.38	0.61	26.83	19.00	12.50	16.08	6.29	10.68
K_{100}	1.47	0.42	0.64	25.42	17.08	10.00	18.05	7.64	12.29
K_{150}	1.55	0.48	0.71	23.33	16.17	8.25	21.33	8.58	13.04
CD (P=0.05)	0.08	0.04	0.03	2.21	1.91	1.26	0.61	0.33	0.99
Zn level (kg ha^{-1})									
Zn_0	1.31	0.36	0.59	22.33	17.38	11.00	16.96	6.78	10.42
Zn_{10}	1.52	0.45	0.67	29.29	18.79	13.00	17.42	7.17	12.19
CD (P=0.05)	0.06	0.03	0.02	1.56	1.35	0.89	0.43	0.23	0.70
B level (kg ha^{-1})									
B_0	1.39	0.39	0.62	25.00	17.29	11.33	16.83	6.84	10.21
B_1	1.45	0.42	0.64	26.63	18.88	12.67	17.55	7.10	12.40
CD (P=0.05)	0.06	0.03	0.02	1.56	1.35	0.89	0.43	0.23	0.70

content may be ascribed to increased availability of boron through the addition of borax.

After harvesting

Potassium

Potassium content varied from 0.31 to 0.55 per cent (K_0) and 0.48 to 0.71 per cent (K_{150}) in grain and straw, respectively. The increase in K content in grain and straw may be attributed to supply of potassium through applied K.

Like K application, addition of Zn increased K content in grain and straw significantly. Compared to 0.36 and 0.59 per cent K in grain and straw at Zn_0, respectively, application of Zn @ 10 kg ha^{-1} recorded 0.45 and 0.67 per cent K, in grain and straw, respectively. Application of boron significantly influenced the K content in wheat grain and straw. Potassium content increased with the application of boron because the latter depresses the uptake of Ca which might have antagonistic effect on K as reported by Reeve and Shive (1994).

Zinc

Application of K @ 100 and 150 per cent of recommended dose decreased Zn content in grain and straw significantly. This might be due to the antagonistic relationship between K and Zn. Unlike K application, Zn application resulted in significant increase in Zn content of grain and straw in wheat. Application of Zn @ 10 kg ha^{-1} recorded 18.79 and 13.00 mg kg^{-1} Zn in grain and straw, respectively. The increase in Zn content with the application of Zn is understandable. Like Zn, B application influenced the zinc concentration in wheat positively. Application of B (1 kg ha^{-1}) recorded Zn content of 18.88 and 12.67 mg kg^{-1} in grain and straw, respectively. Zn contents at B_0 were17.29 and 11.33 mg kg^{-1} in grain and straw, respectively.

Boron

The contents in grain varied from 5.37 to 8.58 mg kg^{-1} under K_0 and under the treatment receiving super optimal dose of K (K_{150}), respectively. The corresponding values were 9.21 and 13.04 mg kg^{-1}in straw. Ujwalaranade Malvi (2011) has reported that since K and B have many overlapping physiological roles, their relationship is understood to be synergistic.

Likewise, application of Zn @ 10 kg ha^{-1} enhanced the boron content in wheat grain and straw significantly. Zn contents in grain and straw at Zn_{10} were 7.17 and 12.19 mg kg^{-1}, respectively. Whereas, the respective contents were 6.78 and 10.42 mg kg^{-1} when no Zn was applied. In case of B application also, the effect on B content was found positive and significant (Table 4.12). Here, B contents at B_1 were 7.10 and 12.40 mg kg^{-1} in grain and straw, respectively. Whereas, B_0 recorded 6.84 and 10.21 mg kg^{-1}B content in grain and straw, respectively. The positive and significant influence on B content may be attributed to its supply through borax.

Effect of potassium, zinc and boron on nutrient uptake

Potassium

Graded levels of K influenced the total K uptake significantly. Total K uptake varied from a minimum value of 34.71 kg ha^{-1}under no K application to 68.16 kg ha^{-1} under 150 per cent of recommended dose of K. The data further revealed that application of 50, 100 and 150 per cent of recommended dose of K resulted in 27.4, 59.4 and 96.4 per cent higher total K uptake over no K application, respectively (Table 3). The significant increase in total K uptake with the application of K may be attributed to the better availability of this nutrient due to direct supply through muriate of potash.

Regarding Zn, its application @ 10 kg ha^{-1} recorded 56.91 kg ha^{-1} total K uptake compared to 44.71 under Zn_0, thereby, resulting in an increase of 27.3 percent. It might be due to synergistic effect on the root development which increased the K uptake from the soil through diffusion and mass flow from the immediate vicinity of plant roots (Umar *et al.* 2003).

Boron application led to significant increase in the total K uptake. Application of B @ 1 kg ha^{-1} recorded total K uptake of 53.31 kg ha^{-1} in comparison to 48.31 kg ha^{-1} under no boron application. Such increase in K uptake due to the application of B has also been reported by Kaur (2012).

Zinc

Application of potassium had non-significant effect on total zinc uptake. Unlike K, application of Zn influenced total Zn uptake positively and significantly. There was an increase of 24.9 per cent with the application of Zn @10 kg ha^{-1} over no Zn application. Increase in zinc uptake with zinc application may be due to role of zinc in auxin synthesis and meristematic activities (Das 2011). The results further indicated that application of B resulted in significant increase in total Zn uptake (Table 4.17). Compared to uptake value of 120.76 g ha^{-1}under B_0, application of B @ 1 kg ha^{-1} recorded total Zn uptake of 139.20 g ha^{-1}. Similar increase in Zn uptake with the application of B has also been recorded by Annie and Duraisami (2005).

Boron

Total B uptake increased significantly with the application of 50, 100 and 150 per cent of recommended dose of K. The values being 75.94, 104.44 and 124.29 g ha^{-1}, respectively. This might be due to the synergistic relationship of K with B as these nutrients have some common physiological functions in plant system (Ujwalaranade Malvi 2011).

Irrespective of K and B, application of Zn increased total B uptake significantly. The values of total B uptake under no Zn application and Zn application @ 10 kg ha^{-1} were 80.78 and 100.57 g ha^{-1}, respectively. Similar increase in B uptake with the application of Zn has also been recorded by Kaur (2012).

Total B uptake increased significantly with the application of B. Compared to 81.40 g ha^{-1} under no B, application of B @ 1 kg ha^{-1} recorded total B uptake of 99.95 g ha^{-1}. The increase in B uptake may be attributed to direct addition of B through borax in the present study.

Effect of potassium, zinc and boron on potassium use efficiency

The results pertaining to effect of K, Zn and B on efficiency indices like partial factor productivity (PFP), agronomic efficiency (AE), physiological efficiency (PE) and apparent recovery (AR) have been depicted in table 4. A reference to the data revealed that partial factor productivity (PFP) varied from 113.37 to 279.26 under 50 per cent of recommended dose of K.

Partial factor productivity decreased with the increasing level of K. Similar trends in the partial factor productivity with the increasing levels of K has also been recorded by Surekha *et al.* (2003) and Billore *et al.*(2009) in the soils of Hyderabad (Andhra Pradesh) and Indore (Madhya Pradesh), respectively. Application of Zn @ 10 kg ha^{-1} increased PFP from 137.37 to 144.56 kg grain kg^{-1} K applied. In case of boron, the increase in PFP was by about 13 kg grain kg^{-1} K applied. The increase in PFP with the use of Zn and B might be possibly due to their different physiological roles in growth and development of the plants.

Physiological efficiency (PE) varied from 41.02 under 150 per cent of recommended dose of K to 52.83 kg grain kg^{-1} K uptake under 50 per cent of recommended dose of K. Like PFP, physiological efficiency decreased when application of K was increased from 50 per cent of the recommended dose to 150 per cent. These results confirm the findings of Shivay *et al.* (2002), Surekha *et al.* (2003) and Billore *et al.* (2009). A slight increase was observed with the application of Zn. Whereas, a decrease was noted with the application of B.

Regarding the agronomic efficiency (AE), it was observed that each successive increment in K level recorded lower AE value than preceding one. The values were 42.53, 39.88 and 34.46 kg grain kg^{-1} K applied under 50, 100 and 150 per cent of recommended dose of K, respectively (Table 4). Application of Zn @ 10 kg ha^{-1} increased the AE from 28.30 to 30.14 kg grain kg^{-1} K applied. Similar increase in AE with the application of Zn has also been reported by Sriramachandrasekharan *et al.* (2009). Whereas, application of B decreased AE marginally.

Apparent recovery (AR) varied from a minimum value of 76.22 to maximum value of 89.16 per cent. Application of 50 per cent of recommended K recorded lowest value and 150 per cent recorded highest value. Increasing levels of K increased apparent recovery. Similar trend in the apparent recovery with the application of K has also been reported by Shivay *et al.* (2002) A further reference to the data in table 4.19 revealed that Zn application increased apparent recovery from 57.78 to 67.28 per cent. Similar increase in apparent recovery with the application of Zn has also been recorded by Sriramachandrasekharan *et al.* (2009) in the soils of Annamulai Nagar of Tamil Nadu. About 4 per cent increase in apparent recovery had also been recorded with the application of B @ 1 kg ha^{-1}.

In general, the results of the present investigation demonstrated that Zn application increased partial factor productivity, physiological efficiency, agronomic efficiency and apparent recovery. Whereas, B application enhanced partial factor productivity and apparent recovery only.

Conclusion

Among K levels, highest grain and straw yield of wheat was recorded under 150 per cent of the recommended dose of K. Application of Zn @ 10 kg ha^{-1} resulted in significantly higher grain and straw yield of wheat over no Zn application. B application @ 1 kg ha^{-1} increased grain and straw yield of wheat significantly over no boron application. Graded levels of K increased total N, P, K, Fe, Mn, Cu and B uptake significantly. Application of Zn resulted in significant increase in total N, P, K, Mn, Zn and B uptake. Total uptake of N, P, K and micronutrients (Fe, Mn, Cu, Zn and B) increased with the application of boron @ 1 kg ha^{-1}. Application of Zn increased potassium use efficiency indices i.e. partial factor productivity, physiological efficiency, agronomic efficiency and apparent recovery. B application increased partial factor productivity and apparent recovery.

Table 3. Effect of potassium, zinc and boron on K, Zn and B uptake

Treatment	K ($kg\ ha^{-1}$)			Zn ($g\ ha^{-1}$)			B ($g\ ha^{-1}$)		
	Grain	Straw	Total	Grain	Straw	Total	Grain	Straw	Total
K level (% of recommended)									
K_0	9.34	25.37	34.71	59.51	78.64	138.15	15.91	42.14	58.05
K_{50}	13.40	30.81	44.21	66.79	62.78	129.57	22.07	53.87	75.94
K_{100}	16.73	38.60	55.33	67.44	60.45	127.89	30.26	74.18	104.44
K_{150}	20.59	47.57	68.16	68.69	55.62	124.31	36.53	87.76	124.29
CD(P=0.05)	1.37	2.42	3.10	NS	7.83	NS	2.27	6.55	7.70
Zn level ($kg\ ha^{-1}$)									
Zn_0	12.78	31.93	44.71	60.10	55.53	115.62	24.08	56.70	80.78
Zn_{10}	17.67	39.24	56.91	71.12	73.22	144.34	28.30	72.27	100.57
CD(P=0.05)	0.97	1.71	2.19	6.10	5.54	9.47	1.60	4.63	5.44
B level ($kg\ ha^{-1}$)									
B_0	14.38	33.93	48.31	61.59	59.17	120.76	25.00	56.40	81.40
B_1	16.07	37.25	53.32	69.63	69.57	139.20	27.38	72.57	99.95
CD(P=0.05)	0.97	1.71	2.19	6.10	5.54	9.47	1.60	4.63	5.44

Table 4. Effect of potassium, zinc and boron on potassium use efficiency

Treatment	PFP (kg grain kg^{-1} K applied)	PE (kg grain kg^{-1} K uptake)	AE (kg grain kg^{-1} K applied)	AR (%)
K level (% of recommended)				
K_0	--	--	--	--
K_{50}	279.26	52.83	42.53	76.22
K_{100}	171.26	50.74	39.88	82.48
K_{150}	113.37	41.02	34.46	89.16
Zinc level ($kg\ ha^{-1}$)				
Zn_0	137.37	35.82	28.30	57.78
Zn_{10}	144.56	36.47	30.14	67.28
B level ($kg\ ha^{-1}$)				
B_0	134.31	38.07	29.58	60.44
B_{10}	147.63	34.22	28.86	64.62

PFP (partial factor productivity), AE (agronomic efficiency), PE (physiological efficiency) and AR (apparent recovery)

References

Abbas G, Khan MQ, Jamil M, Tahir M and Hussain F 2009. Nutrient uptake, growth and yield of wheat (*Triticum aestivum*) as affected by zinc application rates. International Journal of Agriculture and Biology **11**: 389–396.

Billore SD, Ramesh A, Vyas AK and Joshi OP 2009. Potassium use efficiencies and economic optimization as influenced by levels of potassium and soybean (*Glycine max*) genotypes under staggered planting. Indian Journal of Agricultural Sciences **79** (7): 510-514.

Black CA 1965. *Methods of Soil Analysis. Part II.* Chemical and mineralogical properties. American Society of Agronomy, Madison, Wisconsin, USA.

Das DK 2011. *Introductory Soil Science*. Kalyani Publishers, New Delhi, India.

Duraisamy P, Kothandaraman GV and Chellamuthu S 1988. Effect of amendments and zinc on the availability, content and uptake of zinc and iron by rice bhavani in sodic soil. Madras Agricultural Journal **75** (3-4): 119-124.

Hatcher JT and LV Wilcox 1950. Colorimetric determination of boron using carmine. Analytical Chemistry **22**:567-569.

Hossain L, Asad-ud-doullah M, Kundu S 2002. Interaction and mean effects of boron and varieties on agronomic, seed quality and yield contributing character of wheat. Bangladesh Journal of Agricultural Sciences **29** (1): 69-73.

Jackson ML 1967. *Soil Chemical Analysis*. Prentice Hall of India Ltd. New Delhi. pp 219-221.

Kaur R 2012. Influence of zinc and boron on wheat productivity and phosphorus use efficiency in an acid Alfisol. *M.Sc.Thesis*. Department of Soil Science, CSK Himachal Pradesh Krishi Vishvavidyalaya, Palampur, India.

Mishra SK 2003. Effect of sulphur and potassium on yield, nutrient uptake and quality characteristics of mustard (*Brassica juncea*) in Udic Haplustepts of Kanpur. Journal of the Indian Society of Soil Science **51**: 544-548.

Raghav RS, Chauhan SK and Singh SK 2011. Response of wheat (*Triticum aestivum*) cultivars to potassium application. Annuals of Agriculture Research New Series **32** (1&2):59-60.

Shaheen R, Samim MK and Mahmud R 2007. Effect of zinc on yield and zinc uptake by wheat on some soils of Bangladesh. Journal of Soil and Nature **1**(1): 7-14.

Shivay YS, Hong Chen Jin and Shouren D 2002. Studies on genotypic variation for potassium utilization efficiency in barley (*Hordeum vulgare* L.) genotype under low available soil potassium condition. Journal of Potassium Research **18**: 42-46.

Shukla AK, Dwivedi BS, Singh VK and Gill MS 2009. Macro role of micronutrients. Indian Journal of Fertilizers **5** (5): 11-12, 15-18.

Sharma PK, Sharma SP and Jain P. 2001. Nutrient mining in different climatic zones of Himachal Pradesh. Fertilizer News **46** (8): 69-74.

Singh MV. 2009. Micronutrient nutritional problems in soils of India and improvement for human and animals health. Indian Journal of Fertilizers **5**(4): 11-26.

Sriramachandrasekharan MV, Soundarajan R and Ravichandran M 2009. Proceedings IPI-QUAT-IPNI International Symposium on potassium role and benefits in improving nutrient management for food production, quality and reduced environmental damages, Bhubaneshwar (Orissa), India.

Surekha K, Narayana Reddy M, Balasubramanian V 2003. Effect of potassium application on yield and nutrient use efficiency of rice hybrids and conventional varieties. Journal of Potassium Research **19**:55-60.

Ujwalaranade Malvi 2011. Interaction of micronutrients with major nutrients with special reference to potassium. Karnataka Journal of Agricultural Science **24** (1): 106-109.

Umar Khan M, Quasim M, Subhan M, Jamil M and Ahmad RD 2003. Response of rice to different methods of zinc application in calcareous soils. Pakistan Journal of Applied Science **3**: 524-529.

Yadav RL and Yadav B 2004. Effect of soil compaction and potassium fertilization on yield and water expense efficiency of pearl millet in loamy soil. Journal of the Indian Society of Soil Science **52**: 192-193.

Yadav SS, Tikkoo A and Singh JP 2012. Effect of potassium on Pearl millet-Wheat Cropping system in coarse textured soils of Southern Haryana. Journal of the Indian Society of Soil Science **60** (2): 145-149.