Journal of Pharmacognosy and Phytochemistry

Available online at www.phytojournal.com

E-ISSN: 2278-4136
P-ISSN: 2349-8234
JPP 2018; 7(2): 287-291
Received: 01-01-2018
Accepted: 02-02-2018

Syed Talib Hussain
Research Scholar, Mountain Research Centre for Field Crops, Sher-e-Kashmir University of Agricultural Sciences and Technology of Kashmir, Khudwani Campus, Jammu and Kashmir, India

Mohd Anwar Bhat
Mountain Research Centre for Field Crops, Sher-e-Kashmir University of Agricultural Sciences and Technology of Kashmir, Khudwani Campus, Jammu and Kashmir, India

Ashaq Hussain
Mountain Research Centre for Field Crops, Sher-e-Kashmir University of Agricultural Sciences and Technology of Kashmir, Khudwani Campus, Jammu and Kashmir, India

Showket Ah. Dar
Division of Genetics and Plant Breeding, Shere-e-Kashmir University of Agricultural Sciences and Technology of Kashmir, Jammu and Kashmir India

Sajad Hussain Dar
Mountain Research Centre for Field Crops, Sher-e-Kashmir University of Agricultural Sciences and Technology of Kashmir, Khudwani Campus, Jammu and Kashmir, India

Manzoor A Ganai
Mountain Research Centre for Field Crops, Sher-e-Kashmir University of Agricultural Sciences and Technology of Kashmir, Khudwani Campus, Jammu and Kashmir, India

NA Telli
Mountain Research Centre for Field Crops, Sher-e-Kashmir University of Agricultural Sciences and Technology of Kashmir, Khudwani Campus, Jammu and Kashmir, India

Correspondence
Syed Talib Hussain
Research Scholar, Mountain Research Centre for Field Crops, Sher-e-Kashmir University of Agricultural Sciences and Technology of Kashmir, Khudwani Campus, Jammu and Kashmir, India

Zinc fertilization for improving grain yield, zinc concentration and uptake in different rice genotypes

Syed Talib Hussain, Mohd Anwar Bhat, Ashaq Hussain, Showket Ah. Dar, Sajad Hussain Dar, Manzoor A Ganai and NA Telli

Abstract
A pot experiment was conducted in the experimental farm of Mountain Research Centre for Field Crops (MRCFC), Khudwani of Sher-e-Kashmir University of Agricultural Sciences & Technology of Kashmir. The experimental soil was slity clay loam, low in available N, medium in P and K and deficient in Zn with neutral pH, and was laid out in completely randomised design (CRD) with three replications to study the response of varying Zn concentrations (0, 5, 10, 15 and 20 mg Zn kg^{-1} soil) in four rice genotypes (Jhelum, SR1, China 1007 and China1039). Genotypes differed significantly in grain yield.Among the genotypes SR1 gave significantly higher grain yield over Jhelum and both out yielded the rest two genotypes. Increase in Zn concentration due to the progressive increase in Zn levels to 5, 10, 15 and 20 mg Zn kg^{-1} was 43.5, 71.5. 79.5 and 80.4% over control during the year 2011, respectively. The corresponding figures during the year 2012 were 47.8, 68.8, 74.8, 78.9%, respectively. Overall Zn concentration in brown rice, hull, straw and roots was of the order of China 1039>Jhelum>China 1007>SR1. Among the genotypes China 1039 and Jhelum gave better response to higher levels of Zn with regard to Zn content in brown rice.

Keywords: zinc, rice, fertilization, genotypes

Introduction
Rice (*Oryza sativa* L.) is the main staple food of around half of world's population. On a global basis, rice provides 21 and 15% per captia dietary energy and protein, respectively. Rice is one of highly sensitive crops to zinc deficiency, and zinc is the most important micronutrient limiting rice growth and yield. Zinc deficiency is prevalent worldwide both in temperate and tropical climate (Fageria *et al.*, 2003) [1]. Zinc deficiency is a well documented problem in food crops, causing decreased crop yields and nutritional quality. Increasing incidences of Zn deficiency over the past several years have been due to various reasons. These include increased crop demand on soils ability to supply Zn fast enough as a result of improved cultivars and management, use of urea in place of acid fertilizer ammonium sulphate, increased use of phosphate fertilizers and the resulting P induced Zn deficiency; and the use of alkaline irrigation water without proper drainage. It is anticipated that further increase in incidences with the advent of rice with Zn dense grains for human nutrition which will have greater Zn requirement (Welch and Graham, 1999) [2]. An analysis of 2, 33,003 soil samples taken from different states showed that 47 per cent of Indian soils are deficient in Zn (Takkar, 1996). Analysis of 25,000 plant samples collected from different states in India showed that 44% of the plant samples contained inadequate Zn (Singh, 2007). These values indicate that Zn deficiency in soils represents a particular constraint to crop yield and a major reason for the low dietary intake of Zn.

Application of Zn fertilizers or Zn- enriched NPK fertilizers (agronomic biofortification) offers a rapid solution to the problem. Soil application of Zn increased grain Zn concentrations in various cereal crops by a factor of two to three, depending on species (Moraghan, 1994) and crop genotype (Singh, 1992). Soil type also influences the extent of increase in Zn concentration in grain as consequence of soil Zn fertilization. Soil low in CEC (Rengel and Graham, 1995) [6] does not bind Zn well, leaving a relatively greater proportion of fertilizer Zn in the plant available form, thus allowing for a considerable increase in grain Zn concentration with an increase in Zn fertilization to 3.2 mg Zn kg^{-1} soil (up to 145 mg Zn kg^{-1} grain).

Response of rice to zinc has been reported by several workers in India (Singh and Abrol, 1986; Shivay *et al.*, 2008 a, b) [8, 9, 10]. Zn deficiency in cereal plants is a well-known problem that causes reduced agricultural productivity all over the world (Cakmak *et al.*, 1999) [11].

Keeping in view the importance of zinc fertilization, a pot experiment was conducted to study the response of rice genotypes to zinc fertilization in a zinc deficient soil.

Materials and Methods

A pot experiment was conducted in the experimental farm of Mountain Research Centre for Field Crops (MRCFC), Khudwani of Sher-e-Kashmir University of Agricultural Sciences & Technology of Kashmir. The experimental site is situated in temperate zone of Jammu and Kashmir State between 34º N latitude and 74º E longitude at an altitude of 1560 m above mean sea level. The experiment was conducted during kharif 2011 and 2012 on slity clay loam soil, neutral in pH(6.78), low in nitrogen(215 kgha^{-1}), medium in available phosphorus(14.2kg ha^{-1}),and potassium(205kg ha^{-1}), and deficient in zinc(0.62mg kg^{-1})

Soil from the top 15 cm was collected randomly from experimental farm. The soil was mixed thoroughly to make a uniform medium in all respects and shade dried. Five kg of soil was filled in pots of 6 L capacity each. Before filling the pots Zn treatment was given in solution form. To acquire the desired Zn soil concentration of 5, 10, 15 and 20 mg kg^{-1}; 60, 120, 180 and 240 mg of $ZnSO_4.H_2O$ was dissolved in 250 ml of water. Analytical grade $ZnSO_4.H_2O$ was dissolved in water to make a uniform solution that was sprinkled on soil with constant stirring for each pot. Each treatment was given to the pots in triplicate and the experiment was laid out in completely randomized design (CRD). The pots were given small quantity of water daily to avoid leaching of nutrients. The N, P and K fertilizer was given to each pot as the recommended dose fertilizers on soil weight basis. To determine the grain and straw yield, crops were harvested at maturity. Dried grain and sample were grounded and digested in triple acid mixture and zinc concentration was determined in atomic absorption spectrometer. Zinc uptake in grain and straw was calculated by multiplying the grain and straw yield with respective zinc concentration.

Results and Discussion

Grain and straw yield

Grain and straw yield of rice responded significantly due to zinc application. (Table 1) On an average, the grain yield ranged between 49.0 to 62.2 g pot^{-1}and straw yield ranged from 88.05 to 96.55 g pot^{-1} due to zinc application. The highest grain yield 62.45 g pot^{-1} and straw yield 96.55 45 g pot^{-1} was noticed with 15 mg Zn kg^{-1} and minimum grain yield 49.0 and straw yield 88.05 was observed in control (no zinc).The increase in grain yield due to the application of 5 mg kg^{-1} was 23.5 per cent over control. With further increase in Zn levels, the grain yield per pot did not increase significantly. On an average the application of 10, 15 and 20 mg Zn kg $^{-1}$ increased the grain yield by 25.8, 25.2 and 26.0 percent over control, while in straw yield percent increase with application of 5, 10 and 20 mg Zn kg^{-1} was 9.5, 9.5 and 9.3 per cent over control. Zinc application might have stimulated the metabolic and photosynthetic activity which resulted in higher vegetative growth and yield attributes. This was ultimately translated into higher grain yield. For attaining maximum grain yield soil Zn concentrations beyond the critical limits may not be necessary. That might have been the reason for a non significant response beyond 5 mg Zn kg^{-1} soil. Veeranagappa (2010) [12]; Khan *et al*. (2012) [13]. Pooniya and Shivay (2012) [10] and Jat *et al*. (2011) [15] have reported a positive impact of Zn on grain yield in Zn deficient soils. Application of Zn further enhanced the uptake of other major nutrients which might have also enhanced the vegetative growth of rice and ultimately the straw yield. These results confirm the findings of Wijebandara and Iranie. (2008) [16].

The grain and straw yield differed among genotypes. SR-1 gave significantly higher grain and straw yield over Jhelum, China-1007 and China 1039. Data averaged of two years showed that highest grain yield of 67.4 g pot^{-1} and straw yield 105.55 g pot^{-1} was recorded in SR-1 and lowest grain yield of 51.85 g pot $^{-1}$and straw yield138.05 g pot $^{-1}$ was recorded in China-1039. The grain yield realized in SR-1 was 7.2, 24.0 and 30.4 per cent higher as compared to Jhelum, China -1007 and China 1039, respectively. Pandey et al. (2010) [18] reported that variation in the potential grain yield among rice genotypes demonstrated that genotype is an important contributor to overall variability and has to be considered in zinc fertilization management.

Table 1: Effect of zinc levels on grain and straw yield of different rice genotypes

Treatment	Grain yield	(g pot^{-1})	Straw yield	(g pot^{-1})	Biological yield	(g pot^{-1})	HI	(%)
	2011	2012	2011	2012	2011	2012	2011	2012
Zinc levels (mg/kg)								
0	47.7	50.3	86.5	89.6	134.2	139.9	36.5	36.00
5	58.8	62.3	94.1	98.8	152.9	161.1	38.5	38.67
10	59.1	63.6	94.2	98.9	153.3	162.5	38.6	39.14
15	61.2	63.7	94.3	98.8	155.5	162.5	39.4	39.20
20	60.6	62.9	94.1	98.4	154.7	161.3	39.2	39.00
SEm±	2.11	2.22	2.85	2.91	3.77	3.98	1.03	1.01
C.D ($p \leq 0.05$)	4.26	4.49	5.76	5.88	7.62	8.04	NS	NS
Rice genotypes								
Jhelum	60.8	64.9	92.7	97.9	153.5	162.1	39.6	39.86
SR-1	65.6	69.2	102.8	108.3	168.4	177.5	39.0	38.99
China 1007	52.9	55.8	88.9	92.8	141.8	148.7	37.3	37.55
China 1039	50.4	53.3	86.7	89.4	137.1	142.7	36.8	37.35
SEm±	1.88	1.99	2.55	2.60	3.37	3.56	0.92	0.90
C.D ($p \leq 0.05$)	3.81	4.02	5.15	5.26	6.81	7.19	1.80	1.82
SEm±	2.24	2.17	3.29	3.17	4.16	4.10	1.10	1.07
C.D (Zn x genotypes)	NS	NS	NS	NS	NS	NS	NS	NS

Zn concentration

Zn concentration in brown rice

Zinc concentration in brown rice averaged over two years increased from 31.55 to 60.29 mg kg^{-1} with increase in Zn application from 5 to 20 mg Zn kg^{-1} respectively. With each level of increase in the Zn there was a corresponding increase in Zn concentration in the brown rice. However, the increase was significant only upto 15 mg Zn kg^{-1}. So, increase in Zn concentration due to the progressive increase in Zn levels to 5,10,15 and 20 mg Zn kg^{-1} was 43.5, 71.5. 79.5 and 80.4% over control during the year 2011. The corresponding figures for the year 2012 were 47.8, 68.8, 74.8, 78.9%, respectively. The increased Zn concentration in the brown rice was outcome of increased availability, absorption and translocation and deposition of Zn in brown rice. Cakmak (2004) [17] reported similar results.

Genotypes differed significantly in respect of Zn concentration in brown rice. China 1039 had Zn concentration in the brown rice which was significantly higher than all other genotypes. China-1039 recorded significantly higher zinc concentration of 57.65 and 58.1 mg kg^{-1} during the year 2011 and 2012, respectively. Jhelum ranked second in Zn concentration. Overall China 1039>Jhelum>China 1007>SR1 in respect of Zn concentration in brown rice, hull, straw and roots.

Hull Zn concentration

The data indicated that application of zinc levels significantly increased zinc concentration in hull (Table 2). The Zn concentration in hull was slightly higher than that of brown rice. On average zinc concentration in hull ranged from 31.4 to 63.81 mg kg^{-1}. Significantly increase in hull Zn concentration was recorded up to 20 mg Zn kg^{-1}. The percent increase in Zn concentration due to the application of 5, 10, 15 and 20 mg Zn kg^{-1} was 22.6, 62.8, 72.2 and 81.0 mg kg^{-1} over control, respectively, for the year 2011. The corresponding figures for the year 2012 were 34.6, 58.2, 65.7 and 74.4 mg kg^{-1}.

Genotypes differed significantly in respect of Zn concentration in hull. China 10 39 had Zn concentration in the hull which was significantly higher than all other genotypes. China-1039 recorded significantly higher zinc concentration of 57.3 and 55.70 mg kg^{-1} during the year 2011 and 2012, respectively. Jhelum ranked second in hull Zn concentration. Overall China 1039>Jhelum>China 1007>SR1.

There was a significant interaction between the Zn levels and rice genotypes. A significant increase in Zn concentration in hull was recorded up to 15 mg Zn mg kg^{-1} in case of Jhelum and China 1039. However, in case of SR-1 and China 1007 the increase was significant only upto 10 mg Zn kg^{-1}. Highest Zn concentration in hull was recorded in China 1039 at 20 mg Zn kg^{-1}. The interaction was significant during both the years.

Zn concentration in straw

Perusal of the data indicates that that application of zinc significantly increased zinc concentration in the straw over control. The data also reveals that the concentration of Zn in straw is higher than that of hull and brown rice. Data averaged over two years shows that zinc concentration in straw ranged from 43.8 to 86.6 mg Zn kg^{-1}. The increase in Zn concentration in straw was significant with a progressive increase in Zn levels from 0 to 20 mg Zn kg^{-1}. The increase in Zn concentration was to the tune 54.6, 78.7 90.2, 99.3% due to the application of 5, 10, 15 and 20 mg Zn kg^{-1} over control, respectively. The corresponding figures for the year 2012 were 50.8, 73.7, 86.2, and 96.0%, respectively.

Among the different rice genotypes, China-1039 recorded significantly higher zinc concentration (77.95 mg kg^{-1}) over Jhelum, SR-1 and China-1007. The order was similar to that of Zn concentration in hull and brown rice *viz.* China 1039>Jhelum>China 1007>SR1.

There was a significant interaction between the Zn levels and rice genotypes (Table 4.24, 4.25a and 4.25b). A significant increase in Zn concentration in straw was recorded up to 15 mg Zn mg kg^{-1} in case of Jhelum and China 1039. However, incase of SR-1 and china 1007 the increase was significant only upto 10 mg Zn kg^{-1}. Highest Zn concentration in straw was recorded in china 10 39 at 20 mg Zn kg^{-1}. The interaction was significant during both the years.

Root Zn concentration

Roots accumulated the highest concentration of Zn nearly double than that of brown rice (Table 2.). Application of different levels of zinc enhanced its concentration in roots significantly over control. Highest zinc concentration (119.2 mg kg $^{-1}$) was obtained in roots with 20 mg Zn kg^{-1}. Application of 5, 10, 15 and 20 mg Zn kg $^{-1}$ resulted in an increase of 57.8, 76.2, 101.3 and 105.9% increase in the root Zn concentration over control.

Among the different rice genotypes, on an average China 1039 recorded significantly higher zinc concentration (106.2 mg kg^{-1}) over SR-1 and China-1007 in roots, but statistically at par with China -1039. The lowest zinc concentration of 88.85 mg kg^{-1} in roots was recorded in SR-1.

A significant interaction was recorded between Zn levels and rice genotypes. A significant increase in Zn concentration in hull was recorded up to 15 mg Zn mg kg^{-1} in case of Jhelum and China 1039. However, in case of SR-1 and china 1007 the increase was significant only upto 10 mg Zn kg^{-1}. Highest Zn concentration in hull was recorded in china 10 39 at 20 mg Zn kg^{-1}.

The regression analysis between the Zn levels and Zn concentration in brown rice, hull and straw revealed a significant positive relationship. The degree of association measured in terms of R^2 values, average of two years, was 0.971 for brown rice, 0.968 for hull and 0.978 for straw.

Table 2: Effect of zinc levels on Zn concentration (mg kg^{-1}) of different plant parts in rice genotypes.

Treatment	Brown rice		Hulls		Straw		Roots	
	2011	2012	2011	2012	2011	2012	2011	2012
Zinc levels (mg/kg)								
0	30.2	32.9	36.3	31.5	44.7	42.9	59.3	56.6
5	49.1	48.53	44.5	47.8	66.6	62.3	93.6	88.8
10	58.5	53.55	59.1	56.2	81.1	74.5	104.5	104.5
15	61.2	57.54	62.5	59.1	85.7	79.9	119.4	113.1
20	61.7	58.89	63.4	60.2	89.5	84.1	122.1	116.4
SEm±	1.45	1.42	1.30	1.25	1.70	1.64	1.20	1.16
C.D ($p \leq 0.05$)	2.93	2.87	2.63	2.57	3.43	3.22	2.43	2.35

Rice genotypes								
Jhelum	54.6	52.5	54.6	53.20	76.4	69.9	106.4	102.2
SR-1	46.4	45.5	48.4	47.11	66.7	62.82	90.6	87.1
China 1007	47.8	46.8	48.5	47.86	71.0	66.9	93.9	90.2
China 1039	57.2	58.1	57.3	55.70	80.5	75.4	108.3	104.1
SEm±	1.30	1.27	1.16	1.12	1.52	1.53	1.08	1.11
C.D (p≤0.05)	2.62	2.56	2.35	2.30	3.07	2.88	2.18	2.09
SEm±	1.68	1.64	1.51	1.45	1.96	1.85	1.39	1.34
C.D (Zn x genotypes)	NS	NS	5.27	5.06	6.86	6.45	4.86	4.69

Zinc uptake and Zn recovery efficiency (RE%)

The increase in the grain and straw yield and Zn concentration in brown rice, hulls and straw was also reflected in Zn uptake in brown rice, hull, straw and total Zn uptake (Table 3.) There was significant increase in Zn uptake was recorded up to 15 mg Zn kg^{-1}. The increase in Zn rates from 0, 5, 10, 15 and 20 mg kg^{-1} soil resulted in an increase in total Zn uptake to the extent of 77.0, 99.6, 119.8 and 130.4%, respectively, for the year 2011. The corresponding figures for the year 2012 were 73.4, 98.1, 116.4 and 126.4%.

Among the different rice genotypes highest total zinc uptake of 10.48 mg pot^{-1} was recorded in Jhelum which was significantly higher than China-1007 and China-1039 though statistically at par with SR-1.

The data indicated that highest zinc recovery efficiency was realized at 5 mg Zn kg^{-1} of soil which consistently decreased with further increase in Zn levels (). At 5 mg Zn kg^{-1} of soil an average Zn RE of 20% was recorded which decreased to 8.5% at 20 mg Zn kg $^{-1}$ of soil.

Among the genotypes Jhelum appears more efficient in recovery of applied Zn and registered an efficiency of 13% over china 1007. China 1007 was least efficient in term of Zn RE, SR 1 and China 1039 recorded intermediate efficiency of 10.5–11% respectively.

Table 3: Effect of zinc levels on Zn uptake (mg/pot) in brown rice, hull and straw of different rice genotypes

Treatment	Brown rice		Hull		Straw		Total		Zn RE (%)	
	2011	2012	2011	2012	2011	2012	2011	2012	2011	2012
Zinc levels (mg/kg)										
0	1.03	1.16	0.40	0.42	3.83	3.81	5.26	5.37	-	-
5	2.15	2.24	0.70	0.64	6.46	6.36	9.31	9.31	20.25	19.70
10	2.23	2.55	0.77	0.70	7.50	7.31	10.5	10.64	13.10	13.18
15	2.76	2.84	0.87	0.79	7.93	7.89	11.56	11.62	10.50	10.42
20	2.77	2.86	0.91	0.83	8.44	8.37	12.12	12.16	8.58	8.49
SEm±	0.11	0.11	0.049	0.046	0.27	0.26	0.31	0.32	-	-
C.D (p≤0.05)	0.22	0.23	0.098	0.093	0.55	0.54	0.62	0.64	-	-
Rice genotypes										
Jhelum	2.47	2.63	0.80	0.74	7.14	7.12	10.41	10.56	12.88	13.0
SR-1	2.34	2.49	0.74	0.69	6.81	6.76	9.89	10.00	11.58	11.6
China 1007	1.90	2.02	0.66	0.62	6.42	6.31	8.98	9.00	9.30	9.1
China 1039	2.03	2.16	0.72	0.67	6.97	6.81	9.72	9.71	11.15	10.9
SEm±	0.10	0.11	0.04	0.04	0.25	0.27	0.27	0.29	-	-
C.D (p≤0.05)	0.20	0.21	0.087	0.083	0.49	0.54	0.53	0.57	-	-
SEm±	0.13	0.13	0.06	0.06	0.26	0.30	0.29	0.31	-	-
C.D (Zn x genotypes)	NS	NS	NS	NS	1.11	1.01	1.27	1.28	-	-

Conclusion

For achieving the biofortificational benefits in rice, higher dose of Zn upto 20 mg kg^{-1} appears to be more appropriate. Among the genotypes China 1039 and Jhelum responded efficiently to the applied Zn as accumulated in brown rice, hull, straw and roots.

References

1. Fageria NK, Baligar VC. Methodology for evaluation of lowland rice genotypes for nitrogen use efficiency. Journal of Plant Nutrition. 2003; 26:1315-1333.
2. Welch RM, Graham RD. A new paradigm for world agriculture: Meeting human needs, productive, sustainable and nutritious. Field Crops Research. 1999; 60:1-10.
3. Takkar PN. Micronutrient research and sustainable agricultural productivity in India. Journal of the Indian Society of Soil Science. 1996; 44:562-581.
4. Moraghan JT. Accumulation of zinc, phosphorus, and magnesium by navy bean seed. Journal of Plant Nutrition. 1994; 17:1111-1125.
5. Singh K. Critical soil level of zinc for wheat grown in alkaline soils. Fertilizer Research. 1992; 31:253-256.
6. Rengel Z, Graham RD. Importance of seed Zn content for wheat growth on Zn- deficient soil. II: Grain yield. Plant and Soil. 1995; 173:267-274
7. Singh MV. Micronutrient deficiencies in crops and soils in India. In: Micronutrient deficiencies in global crop production. Springer, Berlin, 2007, 93-125.
8. Singh MV, Abrol IP. Transformation and availability of zinc in alkali soils. Fertilizer News. 1986; 31(7):17-27.
9. Shivay YS, Kumar D, Prasad R. Relative efficiency of zinc sulfate and zinc oxide-coated urea in rice-wheat cropping system. Communications in Soil Science and Plant Analysis. 2008a; 39(7, 8):1154-1167.
10. Shivay YS, Kumar D, Prasad R. Effect of zinc-enriched urea on productivity, zinc uptake and efficiency of an aromatic rice-wheat cropping system. Nutrient Cycling in Agroecosystems. 2008b; 81(3):229-243.
11. Cakmak I, Kalayci M, Ekiz H, Bruan HJ, Kiline Y, Yillmaz Y. Zinc deficiency as a practical problem in plant and human nutrition in Turkey: A NATO-science

for stability project. Field Crops Research. 1999; 60:175-188.
12. Veeranagappa P, Prakasha HC, Basavaraja MK, Saqeebulla MH. Effect of zinc enriched compost on yield and nutrient uptake of rice (*Oryza sativa* L.) Europian Journal of Biological Sciences. (*EJBS)*. 2010; 3(1):23-29.
13. Khan P, Yousuf MM, Imtiaz M, Depar N, Aslam M, Muhammad SM et al. Determining the zinc requirements of rice genotype Sarshar evolved at NIA, Tandojam. Sarhad Journal of Agriculture. 2012; 28:1-8.
14. Pooniya V, Shivay YS. Summer green-manuring crops and zinc fertilization on productivity and economics of *Basmati* rice (*Oryza sativa* L.). Archives of Agronomy and Soil Science. 2012; 58(6):593-616.
15. Jat SL, Shivay YS, Parihar CM. Dual purpose summer legumes and zinc fertilization for improving productivity and zinc utilization in aromatic hybrid rice (*Oryza sativa*). Indian Journal of Agronomy. 2011; 56(4):328-333.
16. Wijebandara D, Iranie MD. Studies on distribution and transformation of soil zinc and response of rice to nutrients in traditional and system of rice intensification (SRI) methods of cultivation. Ph.D. thesis submitted Department of Soil Science and Agricultural Chemistry (Department) University of Agriculture Sciences, Dharwad (Institute) AC, Dharwad, Karnataka State, India, 2008.
17. Cakmak I. Identification and correction of widespread zinc deficiency in Turkey-a success story (a NATO Science for Stability Project). Proceedings of the International Fertilizer Society. 2004; 552:1-26.
18. Pandey MP, Verulkar SB, Sharma D. Rice research: Past achievements, present scenario and future thrust. Indian Journal of Agricultural Sciences. 2010; 80(6):447-469.