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Residual effects of dual-purpose summer legumes and zinc fertilization on succeeding wheat in aromatic hybrid rice-wheat cropping system

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Abstract

A field experiment was conducted during 2007-08 and 2008-09 at the research farm of the Indian Agricultural Research Institute, New Delhi; to study the residual effects of dual-purpose summer legumes crops and zinc fertilization on succeeding wheat under aromatic hybrid rice-wheat cropping system. The wheat crop was sown according to aromatic hybrid rice sub-plots on residual fertility and no additional fertilizer was applied to the succeeding wheat. Residual effects of incorporation of dual-purpose summer legumes residue either of cowpea or mungbean and application of 2.0 per cent ZEU ($ZnSO_4.7H_2O$) resulted in higher values of yield attributes, yields, concentrations of Zn in wheat grain, straw and their uptake and net returns of the succeeding wheat. The residual effects of incorporation of mungbean residue resulted in significantly higher grain yield (4.69 and 4.82 t ha^{-1} respectively during 2007-08 and 2008-09) of succeeding wheat which was on par to residual effect of cowpea residue incorporation. Residual effect of application of 2.0 per cent ZEU ($ZnSO_4.7H_2O$) gave higher yield of 4.90 and 5.09 t ha^{-1} during 20007-08 and 2008-09, respectively. The higher net returns by the residual effect of incorporation of mungbean residue and application of 2.0 per cent ZEU ($ZnSO_4.7H_2O$) i.e. ₹ 45,757 and ₹ 51, 212 per ha was recorded during 2007-08 and 2008-09 respectively.

Keywords: Economics, growth parameters, Zn concentrations and their uptake, yield, yield attributes

Introduction

Rice-wheat cropping system covers about 24 million hectares in China, India, Pakistan, Nepal and Bangladesh and zinc deficiency is widespread in rice-wheat belts of all these five countries. The sustainability of this system is at the stake because of declining factor productivity and it is due to continuous deprivation of addition of manures. Sharma *et al.* (1995) reported that *Sesbania* green manuring and mungbean residue incorporation in rice increased grain yield of succeeding wheat by 0.3-0.7 t ha^{-1}. Sharma and Prasad (1999) compared *Sesbania aculeata* and *S. rostrata* and reported that both the species were similar in their effect and increased the succeeding wheat yield by 0.2-0.3 t ha^{-1}. Saha *et al.* (2000) observed that dry matter production of wheat was significantly influenced by preceding green manure crops. Kumar and Sharma (2000) found that *Dhaincha* and blackgram had significant positive effects on the growth and yield attributes of wheat which ultimately resulted in significantly higher grain yield of wheat than control. The dual-purpose short-duration greengram varieties are more profitable than sole green manuring options (Tripathi and Singh, 2007).

Zinc deficiency is prevalent worldwide both in temperate and tropical climate (Slaton *et al.,* 2005 and Shivay *et al.,* 2008b). It is especially widespread in high pH calcareous soils (Liu *et al.,* 1983). An analysis of 0.233 million soil samples taken from different states showed that 47 per cent of Indian soils are deficient in Zn (Takkar, 1996). In India, Zn deficiency is widespread in the rice-wheat cropping system belt of north India, which has high pH calcareous soils (Prasad, 2005; Prasad, 2006 and Shivay *et al.,* 2008b). Increase in soil pH is associated with increased sorption of Zn on soil hydroxides, carbonates and organic matter and increased absorption by plant roots (Rupa and Tomar, 1999). Response of rice to Zn has been reported by several workers in India (Sarkar *et al.,* 1983; Singh *et al.,* 1983), Philippines (Yoshida *et al.,* 1973) and China (Liu *et al.,* 1983; Shihua and Wenqiang, 2000). The general recommendation for rice-wheat cropping system in India is soil application of 10-25 kg zinc sulphate heptahydrate ($ZnSO_4.7H_2O$) to rice (Takkar, 1996), which is quite costly and small farm holders skip it resulting in reduced rice yield. Another factor that discourages the farmers from applying Zn is the poor quality of zinc sulphate heptahydrate marketed in India. An attempt is therefore being currently made by the fertilizer industry in India to produce zinc-coated urea that would allow farmers to apply Zn to rice along with nitrogen. In addition to $ZnSO_4.7H_2O$, ZnO which contains 80 per cent Zn is also being investigated upon for coating urea.

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However, there is a scope to incorporate the dual-purpose summer legumes for their economic production and use of crop residue as a source of nutrients for improved productivity and maintenance of soil fertility. This will also ensure nutritional security of the farmers as their dietary is lacking of the protein in general and ultimately improve their health. So, the present investigation was therefore taken up to quantify the residual effects of dual-purpose legumes and zinc fertilization on productivity, nutrient uptake and economics of succeeding wheat crop grown after aromatic hybrid rice in rice-wheat cropping system.

Material and methods

A field experiment was conducted during 2007-08 and 2008-09 at the research farm of the Indian Agricultural Research Institute, New Delhi, India situated at a latitude of 28°40' N and longitude of 77°12' E, altitude of 228.6 meters above the mean sea level (Arabian sea); to study the residual effects of dual-purpose summer legumes crops and Zn fertilization on succeeding wheat under aromatic hybrid rice-wheat cropping system. The mean annual rainfall of Delhi 650 mm and more than 80 per cent generally occurs during the south-west monsoon season (July-September) with annual mean evaporation 850 mm. The soils of experimental field had 135.5 kg ha^{-1} alkaline permanganate oxidizable N (Subbiah and Asija, 1956), 16.2 kg ha^{-1} available P, 276.5 kg ha^{-1} 1 *N* ammonium acetate exchangeable K and 0.53 per cent organic carbon. The pH of soil was 7.5 (1: 2.5 soil and water ratio) and DTPA extractable Zn (Lindsay and Norvell, 1978) in soil was 0.67 mg kg^{-1} of soil. The critical level of DTPA extractable Zn for rice grown in alluvial soils in rice-wheat belt in north India varies from 0.38- 0.90 mg per kg (Takkar *et al*., 1997).

The experiment was laid out in split plot design with 3 treatments comprising dual-purpose summer grain legume crops residue incorporation i.e. cowpea, mungbean and summer fallow were taken in main plots and 7 treatments of Zn fertilization i.e. absolute control (no N and no Zn), control (only N), 2.0 per cent Zn-enriched urea (ZEU) as $ZnSO_4.7H_2O$, 2.0 per cent ZEU as ZnO, 5 kg Zn ha^{-1} through $ZnSO_4.7H_2O$ as soil application, 5 kg Zn ha^{-1} through ZnO as soil application, CMCU, respectively were allocated in sub-plots and replicated thrice in aromatic hybrid rice. The N @150 kg ha^{-1} were applied in all the treatments except absolute control (no N and no Zn) in aromatic hybrid rice. At final puddling 26 kg P ha^{-1} as SSP and 33 kg K ha^{-1} as MOP were broadcast. N @ 150 kg ha^{-1} as prilled urea or ZEU was applied into 2 equal splits; half at the time of transplanting and remaining half at panicle initiation stage (40 DAT). All Zn fertilization treatments either by Zn-coated urea (2.0% ZEU as $ZnSO_4.7H_2O$ and ZnO) or direct application (as $ZnSO_4.7H_2O$ and ZnO) supplied 5.0 kg Zn ha^{-1} and in one additional treatment coating material coated urea (CMCU) was applied. After harvest of aromatic hybrid rice, wheat variety 'HD 2851' was sown in all the plots in the third week of November in both the years at a row spacing of 22.5 cm with a seed rate of 100 kg ha^{-1}. Since the objective of this study was to quantify the residual effects of dual-purpose summer legumes residue incorporation and Zn applied to aromatic hybrid rice on succeeding wheat, therefore, no chemical fertilizers (NPK or Zn) was added to succeeding wheat. However, all other standard package of practices was followed to raise the wheat crop on residual soil fertility.

Before harvesting of wheat crop all the yield attributing characters like tillers per m^2, grains per spike, grain weight per spike and 1,000-grain weight of wheat were recorded. Wheat was harvested in the last week of April during both the years. At harvest grain and straw yields of wheat were recorded for each plot. Also at harvest, samples of grain and straw were drawn for Zn analysis. Zinc in grain and straw samples was analyzed on a di-acid ($HClO_4$ + HNO_3 in 3:10 ratio) digest on an Atomic Absorption Spectrophotometer (Prasad *et al.,* 2006). Gross returns were calculated based on the grain and straw yield of wheat and their prevailing market prices during the respective crop seasons. Net returns were calculated by subtracting cost of cultivation from gross returns. The data were statistically analysed using general linear model of SAS software.

Results and discussion

Yield attributes of wheat: The number of tillers per m2, grains weight per spike, grains per spike and 1,000-grain weight were significantly better in cowpea residue incorporated plot and followed by mungbean residue incorporated plot while number of grains per spike and 1,000-grain weight were better in mungbean during 2008-09 however these values remained on par with cowpea residue incorporated plot. A residual effect of 2.0 per cent ZEU as $ZnSO_4.7H_2O$ applied to aromatic hybrid rice resulted in highest number of tillers per m^2, grains per spike, grains weight per spike and 1,000-grain weight. But residual effect of 2.0 per cent ZEU as ZnO and 5.0 kg Zn ha^{-1} as $ZnSO_4.7H_2O$ remained on par with 2.0 per cent ZEU as $ZnSO_4.7H_2O$ in all these yield attributing characters except grain weight/spike. All the yield attributes of succeeding wheat were better in second year as compared to first year in all Zn applied treatments except absolute control (no N and no Zn).

The percentage increase in number of tillers m^{-2} at harvest of succeeding wheat due to residual effect of 2.0 per cent ZEU ($ZnSO_4.7H_2O$) was in the order of 12.6 and 19.2; 6.6 and 6.1; 2.1 and 2.3; 1.5 and 2.1; 4.0 and 4.5; 6.6 and 6.1 over absolute control, control, 2.0 per cent ZEU (ZnO), 5.0 kg Zn ha^{-1} ($ZnSO_4.7H_2O$), 5.0 kg Zn ha^{-1} (ZnO) and CMCU during 2007-08 and 2008-09, respectively.

Table 1. Residual effects of dual-purpose summer legumes and zinc fertilization on yield attributes of succeeding wheat under aromatic hybrid rice-wheat cropping system

Treatment	Tillers m^{-2}		Grains/spike		Grains weight / spike (g)		1,000-grain weight (g)	
	2007-08	2008-09	2007-08	2008-09	2007-08	2008-09	2007-08	2008-09
Dual purpose summer legumes								
Summer fallow	310	316	38	39	1.57	1.60	40.77	41.43
Mungbean	328	337	41	43	1.67	1.71	41.84	42.54
Cowpea	333	337	41	42	1.67	1.71	40.47	42.41
SEm±	1.58	1.15	0.23	0.05	0.004	0.010	0.78	0.05
LSD (*P*=0.05)	6.22	4.54	0.91	0.19	0.015	0.040	NS	0.21
Zinc fertilization								
Absolute control (no N & no Zn)	301	292	34	32	1.47	1.37	35.63	37.89
Control (only N)	318	328	38	40	1.62	1.67	41.37	42.27
2.0% ZEU* ($ZnSO_4.7H_2O$)	339	348	44	47	1.72	1.80	42.57	43.53
2.0% ZEU (ZnO)	332	338	42	44	1.67	1.37	42.10	42.97
5.0 kg Zn ha^{-1} ($ZnSO_4.7H_2O$)	334	341	43	45	1.69	1.76	42.20	43.13
5.0 kg Zn ha^{-1} (ZnO)	326	333	41	43	1.67	1.72	41.87	42.83
CMCU**	318	328	38	40	1.62	1.67	41.47	42.28
SEm±	1.44	2.53	0.59	0.67	0.007	0.013	1.24	0.42
LSD (*P*=0.05)	4.42	7.25	1.71	1.92	0.020	0.038	3.56	1.21

*ZEU = Zinc-enriched urea; CMCU** = Coating material coated urea

Table 2. Residual effects of dual-purpose summer legumes and zinc fertilization on productivity of succeeding wheat under aromatic hybrid rice-wheat cropping system

Treatment	Grain yield (t ha^{-1})		Biological yield (t ha^{-1})		Harvest index (%)	
	2007-08	2008-09	2007-08	2008-09	2007-08	2008-09
Dual-purpose summer legumes						
Summer fallow	4.25	4.32	8.87	9.17	48.0	47.2
Mungbean	4.69	4.82	9.73	10.10	48.2	47.7
Cowpea	4.65	4.78	9.68	10.05	48.1	47.6
SEm±	0.02	0.01	0.05	0.02	0.07	0.08
LSD (*P*=0.05)	0.08	0.05	0.19	0.08	NS	0.31
Zinc fertilization						
Absolute control (no N & no Zn)	3.69	3.49	7.62	7.26	48.4	48.0
Control (only N)	4.50	4.61	9.33	9.71	48.2	47.4
2.0% ZEU ($ZnSO_4.7H_2O$)	4.90	5.09	10. 17	10.78	48.0	47.2
2.0% ZEU* (ZnO)	4.70	4.89	9.82	10.31	47.8	47.4
5.0 kg Zn ha^{-1} ($ZnSO_4.7H_2O$)	4.81	4.98	10.03	10.50	47.9	47.4
5.0 kg Zn ha^{-1} (ZnO)	4.64	4.82	9.69	10.15	47.9	47.5
CMCU**	4.52	4.62	9.36	9.71	48.3	47.5
SEm±	0.06	0.05	0.06	0.11	0.54	0.29
LSD (*P*=0.05)	0.18	0.16	0.18	0.33	NS	NS

*ZEU = Zinc-enriched urea; CMCU** = Coating material coated urea

Residual supply of the nutrients from the dual-purpose summer legumes residue incorporation and applied Zn to aromatic hybrid rice in the proper amount and also in synchronized manner might have led to increased growth and development of succeeding wheat and finally resulted into higher yield attributes.

Yields of wheat: The grain and biological yield of succeeding wheat was significantly higher in mungbean residue incorporated plot as compared to summer fallow however it was on par with cowpea residue incorporated plot during both the years of study (Table 2). The harvest index of succeeding wheat was significantly better in mungbean residue treated plot and it remained on par with cowpea during 2008-09. The percentage increase in grain yield of wheat due to residual effect of mungbean residue incorporation was in order of 10.4 and 0.9; 11.6 and 0.8 over summer fallow and cowpea residue treated plot respectively during 2007-08 and 2008-09.

The grain, straw and biological yield of succeeding wheat was significantly influenced by the residual effect of the Zn fertilization treatments applied to aromatic hybrid rice.

The highest grain yield 4.90 and 5.09 t ha^{-1} in 2007-08 and 2008-09, respectively was recorded in 2.0 per cent ZEU as $ZnSO_4.7H_2O$, which was significantly superior over rest of the Zn fertilization treatments applied to aromatic hybrid rice except it remained on par with 5.0 kg Zn/ha as $ZnSO_4.7H_2O$ during both the years of field study. The percentage increase in grain yield of succeeding wheat due to residual effect of 2.0 per cent ZEU ($ZnSO_4.7H_2O$) was in the order of 32.8 and 45.8; 8.9 and 10.4; 4.3 and 4.1; 1.9 and 1.2; 5.6 and 5.6; 8.4 and 10.2 over absolute control, control, 2.0 per cent ZEU (ZnO), 5.0 kg Zn ha^{-1} ($ZnSO_4.7H_2O$), 5.0 kg Zn ha^{-1} (ZnO) and CMCU during 2007-08 and 2008-09, respectively. Almost similar trend was also observed in terms of straw and biological yield of succeeding wheat. Overall, the grain yield of wheat was higher in second year as compared to first year in all residual Zn fertilization treatments except absolute control (no N and no Zn).

This could be attributed due to more residual nutrients availability to succeeding wheat crop from the summer legumes residues incorporation as compared to summer fallow and resulted into higher value of yield attributes, which led to increased yields of succeeding wheat. These results are in good agreement with Sharma *et al.* (1995) and Kumar and Sharma (2000). Higher values of the yield attributes in the Zn-enriched urea plots and further better partitioning of photosynthates due to more and regular supply of N and Zn for longer period to the wheat crop might have resulted into increase in grain yield over rest of the no Zn applied treatments under field study. These results are in agreement with those reported by Shivay *et al.* (2008b).

Zinc concentrations and uptake: Cowpea residue incorporated plot exerted significant residual effect over summer fallow which led to higher grain and straw Zn concentrations and its uptake by succeeding wheat crop during both the years of field study. Application of 2.0 per cent ZEU ($ZnSO_4.7H_2O$) in aromatic hybrid rice resulted in significantly highest residual effect on succeeding wheat in terms of Zn concentration and its uptake by succeeding wheat during both the years of field study.

Table 3. Residual effects of dual-purpose summer legumes and zinc fertilization on zinc concentration and uptake in wheat grain and straw aromatic hybrid rice-wheat cropping system

Treatment	Zn concentration in grain (mg kg^{-1} DM)		Zn concentration in straw (mg kg^{-1} DM)		Total Zn uptake by wheat grain + straw (g ha^{-1})	
	2007-08	2008-09	2007-08	2008-09	2007-08	2008-09
Dual-purpose summer legumes						
Summer fallow	28.0	27.6	107.7	107.9	618.7	647.0
Mungbean	30.9	32.4	111.3	112.5	708.0	754.1
Cowpea	31.9	33.9	112.3	114.7	715.1	770.5
SEm±	0.58	0.51	0.82	0.86	6.7	6.7
LSD (*P*=0.05)	2.27	2.01	3.24	3.37	26.4	26.5
Zinc fertilization						
Absolute control (no N & no Zn)	25.7	25.5	104.3	104.0	504.5	482.0
Control (only N)	28.3	28.5	108.3	109.3	651.6	691.1
2.0% ZEU* ($ZnSO_4.7H_2O$)	34.3	36.2	115.0	116.8	775.5	849.5
2.0% ZEU (ZnO)	32.3	34.0	113.0	114.8	731.5	790.3
5.0 kg Zn/ha ($ZnSO_4.7H_2O$)	32.3	34.2	113.0	114.9	745.4	805.3
5.0 kg Zn/ha (ZnO)	30.3	32.2	111.0	112.7	702.4	756.8
CMCU**	28.3	28.7	108.3	109.5	653.1	692.2
SEm±	0.65	0.59	2.10	0.97	12.6	9.9
LSD (*P*=0.05)	1.88	1.68	6.04	2.77	36.1	28.3

*ZEU = Zinc-enriched urea; CMCU** = Coating material coated urea

The highest total uptake of Zn i.e. 775.5 and 849.4 g ha^{-1} was observed in the plot treated with 2.0 per cent ZEU ($ZnSO_4.7H_2O$) during 2007-08 and 2008-09, respectively. Although the application of 2.0 per cent ZEU (ZnO) and 5.0 kg Zn ha^{-1} ($ZnSO_4.7H_2O$) was on par with 2.0 per cent ZEU ($ZnSO_4.7H_2O$) in terms of straw Zn concentration and uptake in wheat during both the years and total Zn uptake by wheat during first year of the study. The percentage increases in total Zn uptake by succeeding wheat due to residual effect of 2.0 per cent ZEU ($ZnSO_4.7H_2O$) was in the order of 53.7 and 76.2; 19.0 and 22.9; 6.0 and 7.5; 4.0 and 5.5; 10.4 and 12.2; 18.7 and 22.7 over absolute control, control, 2.0 per cent ZEU (ZnO), 5.0 kg Zn ha^{-1} ($ZnSO_4.7H_2O$), 5.0 kg Zn ha^{-1} (ZnO) and CMCU during 2007-08 and 2008-09, respectively.

Zn-oxide coating of prilled urea showed no significant effect on Zn concentrations in wheat grain. As regards wheat straw coating of urea with 1.0 per cent and 2.0 per cent zinc sulphate or 2.0 ZnO recorded significantly higher Zn concentrations than 0.5 per cent and 1.0 per cent ZnO and 0.5 per cent zinc sulphate-coated urea and uncoated urea (Shivay *et al.,* 2008b). N and Zn interacted positively and have synergistic effect on each other, so application of N through modified Zn sources increased the concentration of Zn in grain and straw over control. These results are similar to those reported by Shivay *et al.* (2008a).

Economics : Data pertaining to gross returns, net returns and B:C ratios of succeeding wheat are presented in Table 4. The highest gross returns, net returns and B:C ratio were recorded when succeeding wheat was grown after the incorporation of mungbean residue but it was on par to cowpea residue incorporated plot, while it was minimum when succeeding wheat was grown after summer fallow in both the years of experimentation.

Table 4. Residual effects of dual-purpose summer legumes and zinc fertilization on economics of succeeding wheat under aromatic hybrid rice-wheat cropping system

Treatment	Gross returns (₹/ha)		Net returns (₹/ha)		Benefit: cost ratio	
	2007-08	2008-09	2007-08	2008-09	2007-08	2008-09
Dual-purpose summer legumes						
Summer fallow	50,780	54,395	38,344	41,620	3.08	3.26
Mungbean	55,890	60,341	43,454	47,566	3.49	3.72
Cowpea	55,520	60,003	43,084	47,228	3.46	3.70
SEm±	261	139	261	139	0.02	0.01
LSD (*P*=0.05)	1,025	545	1,025	545	0.08	0.04
Zinc fertilization						
Absolute control (no N & no Zn)	43,862	43,571	31,426	30,796	2.53	2.41
Control (only N)	53,578	57,838	41,142	45,063	3.31	3.53
2.0% ZEU* ($ZnSO_4.7H_2O$)	58,193	63,987	45,757	51,212	3.68	4.01
2.0% ZEU (ZnO)	56,146	61,407	43,710	48,632	3.51	3.81
5.0 kg Zn/ha ($ZnSO_4.7H_2O$)	57,401	62,529	44,965	49,754	3.62	3.89
5.0 kg Zn/ha (ZnO)	55,474	60,469	43,038	47,694	3.46	3.73
CMCU**	53,791	57,922	41,355	45,147	3.33	3.53
SEm±	537	665	537	665	0.04	0.05
LSD (*P*=0.05)	1,539	1,907	1,539	1,907	0.12	0.15

*ZEU = Zinc-enriched urea; CMCU** = Coating material coated urea

Residual effect of Zn fertilization had significant effect on gross returns, net returns and B:C ratio of succeeding wheat. The gross returns, net returns and B:C ratio recorded significantly higher with 2.0 per cent ZEU ($ZnSO_4.7H_2O$) during both the years of study and lowest with absolute control (no N and no Zn). The highest gross returns, net returns and B:C ratio of succeeding wheat production i.e. ₹ 58,193 and 63,987; ₹ 45,757 and 51,212; 3.68 and 4.01 during 2007-08 and 2008-09, respectively were recorded with 2.0 per cent ZEU ($ZnSO_4.7H_2O$). The percentage increases in net returns with 2.0 per cent ZEU ($ZnSO_4.7H_2O$) were in the order of 45.6 and 66.3; 11.2 and 13.6; 4.7 and 5.3; 1.8 and 2.9; 6.3 and 7.4; 10.6 and 13.4 over absolute control, control, 2.0 per cent ZEU (ZnO), 5.0 kg Zn ha^{-1} ($ZnSO_4.7H_2O$), 5.0 kg Zn ha^{-1} (ZnO) and CMCU during 2007-08 and 2008-09, respectively. The similar trend was recorded with regard to gross returns of succeeding wheat production in both the years of experimentation.

Tripathi and Singh (2007) also reported almost similar findings as is accordance to present study. These results are in agreement with Shivay *et al.* (2008b) who also reported the similar findings.

Based on the two years of study it is concluded that the residual effect of legume residue incorporated either of cowpea or mungbean resulted in higher value of yield attributes, yields, concentrations and uptake of Zn and net returns from the succeeding wheat crop compared to summer fallow. Residual effect of 2.0 per cent ZEU ($ZnSO_4.7H_2O$) applied in the aromatic hybrid rice resulted in better residual effect on succeeding wheat crop and gave higher value of yield attributes, yields, concentrations and uptake of Zn and net returns of the succeeding wheat during both the years of study over rest of the treatments applied to aromatic hybrid rice.

References

1. Kumar B and Sharma RPR (2000). Effect of preceding crops and nitrogen rates on growth and yield attributes of wheat. *Indian Journal of Agricultural Research* **34**(1): 34-38.
2. Lindsay WL, and Norvell WA (1978). Development of DTPA soil test for zinc, iron, manganese and copper. *Soil Science Society of America Journal* **42**: 421-428.
3. Prasad R (2005). Rice-wheat cropping systems. *Advances in Agronomy* **86**: 255-339.
4. Prasad R (2006). Zinc in soils and in plants, human & animal nutrition. *Indian Journal of Fertilizers* **2**(9):103-119.
5. Rupa TR, and Tomar KP (1999). Zinc desorption kinetics as influenced by pH and phosphorus in soils. *Communication in Soil Science and Plant Analysis* **30**: 1951-1962.
6. Saha RR, Rai RK and Mukherjee PK (2000). Effect of green manuring of dhaincha and phosphorus on growth, yield and phosphorus uptake by wheat. *Indian Journal of Agronomy* **45**(4): 707-710.
7. Sarkar AK, Leelabhai KS, Murali Mohan GV, Subbiah VV, Subbarao IV and Deb DL (1983). Zinc fertilization of flooded rice in vertisols of Hyderabad. *Journal of Nuclear Research and Agricultural Biology* **12**:96-99.
8. Sharma SN and Prasad R (1999). Effect of *Sesbania* green-manuring and mungbean residue incorporation on productivity and nitrogen uptake of a rice-wheat cropping system. *Bioresource Technology* **87**:171-175.
9. Sharma SN, Prasad R and Singh S (1995). The role of mungbean residues and *Sesbania aculeate* green manure in nitrogen economy of rice-wheat cropping system. *Plant and Soil* **172**: 123-129.
10. Shihua T and Wenqiang F (2000). Nutrient management in the rice-wheat cropping system in the Yangtze river flood plain. In *Soil and Crop Management Practices for Enhanced Productivity of the Rice-Wheat Cropping System in the Sichuan Province of China*; Hobbs PR and Gupta RK(eds.), 24-34, Rice-Wheat Consortium for the Indo-Gangetic Plains, New Delhi, India.
11. Shivay YS, Kumar D and Prasad R (2008a). Relative efficiency of zinc sulfate and zinc oxide-coated urea in rice-wheat cropping system. *Communications in Soil Science and Plant Analysis* **39** (7 & 8): 1154-1167
12. Shivay YS, Kumar D and Prasad R (2008b). Effect of zinc-enriched urea on productivity, zinc uptake and efficiency of an aromatic rice-wheat cropping system. *Nutrient Cycling in Agroecosystems* **81** (3): 229-243
13. Slaton NA, Gbur EE, Wilson CE and Norman RJ (2005). Rice response to granular zinc sources varying in water-soluble zinc. *Soil Science Society of America Journal* **69**:443-452.
14. Subbiah BV and Asija GL (1956). A rapid procedure for the estimation of available nitrogen in soils. *Current Science* **25**(8): 259-260.
15. Takkar PN (1996). Micronutrient research and sustainable agricultural productivity in India. *Journal of the Indian Society of Soil Science* **44**:562-581
16. Takkar PN, Singh MV and Ganeshmurthy AN (1997). A critical review of plant nutrient supply needs, efficiency and policy issues for Indian agriculture for the year 2000: Micronutrients and Trace elements. In: Kanwar JS, and J. C. Katyal, (eds) *Plant Nutrient, Supply Efficiency and Policy Issues: 2000-2025*. National Academy of Agricultural Sciences, New Delhi, India, pp 238-264.
17. Tripathi SC and Singh RP (2007). Effect of chiselling, green-manuring and planting methods on productivity and profitability of rice (*Oryza sativa*) - wheat (*Triticum aestivum*) cropping system. *Indian Journal of Agronomy* **52**(4):161-169.