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Effect of dual-purpose summer legumes and zinc fertilization on system productivity, economics and nutrient use-efficiencies of rice (*Oryza sativa*)– wheat (*Triticum aestivum*) cropping system

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ABSTRACT

A field experiment was conducted during 2007-09 at the research farm of IARI, New Delhi, India; to study the effects of dual-purpose summer legumes and zinc fertilization in aromatic hybrid rice (*Oryza sativa* L.)– wheat (*Triticum aestivum* L.) cropping system. The higher system productivity, N and Zn uptake, nutrient-use efficiencies, net return and B:C ratio were recorded in cowpea [*Vigna unguiculata* (L.) Walp.] or mungbean (*Vigna radiata* L.) residue incorporated plots. The N balance was negative (-) in all treatments but it was least negative (-) in cowpea among summer treatments followed by mungbean. The highest N and Zn uptake, system productivity in terms of grain yield, i.e. 12.32 and 12.71 tonnes/ha was observed with application of 2.0% ZEU ($ZnSO_4.7H_2O$). Among the Zn fertilization treatments the lowest negative (-) balance of N was recorded with control (only N), i.e. -36.92 kg/ha in 2007-08 however in 2008-09 it was recorded with coating material coated urea, i.e. -39.54 kg N/ha over rest of the Zn treatments. The application of 5.0 kg Zn/ha (ZnO) gave the highest (2 696 and 2 601 g/ha during 2007-08 and 2008-09, respectively) positive Zn balance under rice-wheat cropping system. Partial factor productivity, agronomic efficiency, apparent recovery and physiological efficiency of applied N and Zn in rice-wheat cropping system were increased with Zn-enriched urea. The agronomic efficiency of N with 2.0% ZEU ($ZnSO_4.7H_2O$) increased by 49.7% and the N recovery efficiency in grain increased up to 57.6% over normal practice of prilled urea application. With the application of 2.0% ZEU ($ZnSO_4.7H_2O$) the agronomic efficiency of Zn increased in the range of 54 to 160% while Zn apparent recovery (%) in grain increased from 70 to 318% over 2.0% ZEU (ZnO) and 5.0 kg Zn/ha (ZnO), respectively. The dual-purpose summer legume incorporation in rice-wheat system gave higher net returns by 29 to 34% in 2007-08 and 42 to 45% during 2008-09 over summer fallow with B:C ratio up to 3.01. The application of 2.0% ZEU ($ZnSO_4.7H_2O$) gave the highest B:C ratio of 3.02 and increased net returns of aromatic-hybrid rice-wheat system by 11.6 to 12.2% over prilled urea application.

Key words: Net returns, N and Zn use indices, N and Zn economy, Zn oxide-coated urea, Zn sulphate-coated urea

Rice (*Oryza sativa* L.) – wheat (*Triticum aestivum* L.) cropping system covers about 24 million hectares in China, India, Pakistan, Nepal and Bangladesh and zinc deficiency is widespread in these belts of all these countries. The rice-wheat cropping system, which is considered as the backbone of food self-sufficiency, is however facing a sustainability problem due to practices of modern production system with indiscriminate use of chemical fertilizers and pesticides (Prasad 2005). The concerns like declining factor productivity, depletion of soil organic carbon and mineral nutrients content (Prakash *et al.* 2008); waterlogging and salinization, increasing nitrate (NO_3) concentration in well water etc. are the consequences of modern rice-wheat production system with unbalanced and injudicious use of chemical fertilizers and pesticides. Paddy soils are usually deficient in organic matter because of high temperature and moisture, which causes rapid decomposition of organic matter (Mohammad *et al.* 2005).

Green manure crops enhances organic matter which is a most important benefit credited to these crops. The positive effect of green manures on paddy yield has been reported by Sharma and Prasad (1999). Hemalatha *et al.* (1999) observed that *in-situ* incorporation of cowpea before transplanting of rice increased the grain yield by 18% and straw yield by 16% as well as quality of rice. Incorporation of cowpea [*Vigna unguiculata* (L.) Walp.] or other green manuring crops, i.e. mungbean before transplanting of rice can ameliorate the Fe and Mn deficiency by promoting reduced condition besides improving other physico-chemical properties of soil (Nayyar and Chhibba 2000). Sharma *et al.* (1995) reported that *Sesbania* green manuring and

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mungbean residue incorporation in rice increased grain yield of succeeding wheat by 0.3-0.7 tonnes/ha. 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 (Fageria *et al.* 2004). An analysis of 0.233 million soil samples taken from different states showed that 47% 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). 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). Zn deficiency in rice is characterized by burnt dark brown patches of plants which were first reported by Nene (1966). Response of rice to Zn has been reported by several workers in India, Philippines and China. Water solubility of zinc sources is considered an important criterion for zinc availability (Slaton *et al.* 2005). Nayyar *et al.* (1990) from Punjab (India) also showed that zinc oxide was inferior to zinc sulphate both in grain yield and N uptake. However, the solid phase equilibria studies showed that ZnO is reasonably soluble to persist in soil solution and even in calcareous soils of pH 8.0. 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 system productivity. Another factor that discourages the farmers from applying Zn is the poor quality of zinc sulphate heptahydrate marketed in India. Shivay *et al.* (2008b) reported significant improvement in the returns and B:C ratio of rice-wheat cropping system due to application of Zn-enriched urea. Shivay *et al.* (2008a) also reported significant increase in productivity, Zn uptake and Zn-use efficiencies in rice-wheat cropping system due to Zn application with Zn-coated urea. Due to growing food requirement hybrid rice is in high demand but requires more nutrients than prevailing rice varieties.

An attempt was therefore made to produce zinc-coated urea (also referred to as zincated urea), that would allow farmers to apply Zn to rice along with N. In addition to $ZnSO_4.7H_2O$, ZnO which contains 80% Zn is also being investigated upon for coating urea. Further a window period of 70 to 80 days in rice-wheat system provides an opportunity for growing short duration cowpea and mungbean (*Vigna radiata* L.). It is also expected that regular incorporation of dual-purpose summer legumes such as cowpea and mungbean before transplanting of rice may improve not only physico-chemical properties of soil but also enhanced availability of macro and micronutrients in soil. The present investigation was therefore undertaken to quantify the effect of dual-purpose legumes and Zn fertilization on aromatic hybrid rice-wheat system and also to work out system productivity, Zn and N use-efficiencies and their economic feasibility.

MATERIALS AND METHODS

Field experiments were conducted during 2007-08 and 2008-09 in rice-wheat cropping system at research farm of Indian Agricultural Research Institute, New Delhi, 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). The mean annual rainfall of Delhi is 650 mm and more than 80% generally occurs during the south-west monsoon season (July-September) with mean annual evaporation of 850 mm. The soils of experimental field had 135.5 kg/ha alkaline permanganate oxidizable N (Subbiah and Asija 1956), 16.2 kg/ha available P, 276.5 kg/ha 1 *N* ammonium acetate exchangeable K and 0.53% 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 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/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 assigned in main plots and 7 treatments of Zn fertilization, i.e. absolute control (no N and no Zn), control (only N), 2.0% Zn-enriched urea (ZEU) as $ZnSO_4.7H_2O$, 2.0% ZEU as ZnO, 5 kg Zn/ha through $ZnSO_4.7H_2O$ as soil application, 5 kg Zn/ha through ZnO as soil application, CMCU, respectively were allocated in sub-plots and replicated thrice in aromatic hybrid rice. The N @150 kg/ha were applied in all the treatments except absolute control in aromatic hybrid rice. At final puddling 26 kg P/ha as SSP and 33 kg K/ha as MOP were broadcast. N @ 150 kg/ha as prilled urea or ZEU was applied into two equal splits; half at the time of transplanting and remaining half at panicle initiation stage (40 DAT). All Zn fertilization treatments either by coated urea (2.0% ZEU as $ZnSO_4.7H_2O$ and ZnO) or direct soil application (as $ZnSO_4.7H_2O$ and ZnO) supplied 5.0 kg Zn/ha and one additional treatment coating material coated urea (CMCU) was applied. One 25-days-old seedling of an aromatic rice hybrid, i.e. Pusa Rice Hybrid 10 (PRH 10) was transplanted on hills at 20 cm × 15 cm in the first fortnight of July in both the year of study. The plot size was 5.0 m × 1.5 m for each treatment. Rice was grown as per recommended practices and was harvested in the second fortnight of October in both the year of experimentation.

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 of study at a row spacing of 22.5 cm with a seed rate of 100 kg/ha. Since the objective of growing the wheat was to quantify the residual effect of dual-purpose summer legumes residue incorporation and Zn applied to rice on succeeding wheat, no chemical fertilizers (NPK or Zn) was added to wheat. Other recommended package of practices were followed to raise the wheat crop. Wheat was harvested in the last week of April during both the years. The N concentration in rice grain and straw samples were determined by modified Kjeldahl method. Zinc in grain and straw samples was analyzed by di-acid ($HClO_4 + HNO_3$ in 3:10 ratio) digest on an Atomic Absorption Spectrophotometer (Prasad *et al.* 2006).

System productivity was calculated by adding yields of rice and wheat during both the years. The estimated values of partial factor productivity (PFP), agronomic efficiency (AE), recovery efficiency (RE), physiological efficiency (PE) and harvest index (HI) of applied N and Zn were computed as suggested by Fageria and Baligar (2003) and Dobermann (2005). Nutrient balance was calculated by adding of total N/Zn contained in legume residue incorporated into the rice field and nutrient applied to aromatic hybrid rice through chemical fertilizer as total input was subtracted by its total uptake (grain + straw) of N/Zn by rice and wheat. Economics of aromatic hybrid rice-wheat cropping system was calculated based on the prevailing market prices during the respective cropping seasons. Gross returns were calculated based on the grain and straw yield of system productivity and their prevailing market prices during the respective cropping seasons. Net returns were calculated by subtracting cost of cultivation from gross returns while benefit: cost ratio calculated as the ratio of net returns to cost of cultivation.The data were statistically analysed as per the procedure of analysis of variance and significance was tested by "F" test (Gomez and Gomez 1984).

RESULTS AND DISCUSSION

System productivity

The grain and straw productivity of rice–wheat cropping system was significantly higher in cowpea residue incorporated plot as compared to summer fallow but was remained on par to mungbean (Table 1). The percentage increase in system productivity in terms of grain yield due to incorporation of cowpea and mungbean residues was in order of 11.8 and 11.8; 16.7 and 17.0 respectively, during 2007-08 and 2008-09 over summer fallow. This was due to application of summer legumes straw having recycled macro and micro nutrients to top layer form lower soil layer due to their deep root system. They also fixes atmospheric nitrogen that lowers C:N ratio of its straw which also enhances mineralization of native nutrient due to organic acids secretion during its decomposition. The enhanced availability of nutrients by this way in soil due to legume straw incorporation as compared to summer fallow resulted in enhanced crop growth and productivity of rice-wheat system. Similar results were also reported by the Kumar and Sharma (2000) and Nayyar and Chhibba (2000).

The grain and straw productivity of rice–wheat cropping system was significantly higher with 2.0% ZEU ($ZnSO_4.7H_2O$) as compared to rest of the Zn treatments applied to aromatic hybrid rice and its residual effects on the succeeding wheat (Table 1). The increase in grain system productivity with 2.0% ZEU ($ZnSO_4.7H_2O$) was highest over control (only N), i.e. 1.14 and 1.29 tonnes/ha and was lowest with 5.0 kg Zn/ha (ZnO), i.e. 0.44 and 0.51 tonnes/ ha among various Zn application treatments. Overall, increase in the system productivity of aromatic hybrid rice-wheat cropping was more in second year in all treatments except in summer fallow and absolute control, which showed declining trend in system productivity during 2008-09. The percentage increase in system productivity in terms of grain yield of aromatic hybrid rice-wheat cropping system due to direct and residual effect of 2.0% ZEU ($ZnSO_4.7H_2O$) was in the order of 39.4 and 51.5; 10.2 and 11.3; 3.4 and 3.7; 3.4 and 3.9; 5.8 and 6.5; 9.5 and 10.6 over absolute control, control, 2.0% ZEU (ZnO), 5.0 kg Zn/ha ($ZnSO_4.7H_2O$), 5.0 kg Zn/ha (ZnO) and CMCU during 2007-08 and 2008-09, respectively. Almost similar trend was also observed in terms of straw productivity of rice-wheat cropping system under study during both the years.

The continuous and more availability of N and Zn due to coated urea fertilizer; as there was less loss might have contributed for vigorous growth of the crops and ultimately led to higher productivity than uncoated urea. These results are in close agreement with Shivay *et al.* (2008a) who also reported the similar results. However, there was non-significant effect on the harvest index of the system during both the years of study.

NUTRIENT ECONOMY IN RICE-WHEAT CROPPING SYSTEM

Nitrogen economy

Between two dual-purpose summer legumes, N input was highest in the cowpea residue incorporated plots as compared to mungbean and summer fallow while it was same for all treatments except absolute control among Zn fertilization treatments (Table 2). The significantly higher total N uptake (grain + straw) of aromatic hybrid rice-wheat cropping system was recorded when it was grown after incorporation of cowpea residue which remained statistically on par with mungbean residue however, both were superior to summer fallow. Application of 2.0% ZEU ($ZnSO_4.7H_2O$) recorded significantly higher total N uptake (grain + straw) in aromatic hybrid rice-wheat cropping system over all other treatments. Dual-purpose summer legumes and summer fallow resulted in negative (-) balance of N but it was least negative in cowpea residue incorporated plot while highest in summer fallow. Among Zn treatments applied to aromatic hybrid rice, absolute control recorded negative balance which was the highest negative balance of N. However, the least negative balance of N was recorded with control (only N), i.e. -36.92 kg N/ha in 2007-08 but in 2008-09 the least negative N balance was recorded with CMCU, i.e. -39.54 kg N/ha over rest of the Zn fertilization treatments. However, overall N balance was more negative

Table 1 Effect of dual-purpose summer legumes and zinc fertilization on productivity of rice-wheat cropping system

Treatment	Grain yield (tonnes/ha)		Straw yield (tonnes/ha)		Harvest index (%)	
	2007-08	2008-09	2007-08	2008-09	2007-08	2008-09
Dual-purpose summer legumes						
Summer fallow	10.36	10.12	14.26	14.01	42.09	41.95
Mungbean	11.75	12.15	16.18	16.85	42.06	41.89
Cowpea	11.76	12.20	16.30	16.99	41.91	41.78
SEm±	0.02	0.02	0.13	0.12	0.23	0.26
LSD (P=0.05)	0.07	0.10	0.53	0.49	NS	NS
Zinc fertilization						
Absolute control (no N and no Zn)	8.84	8.39	12.44	11.86	41.58	41.47
Control (only N)	11.17	11.42	15.61	16.10	41.75	41.52
2.0% ZEU* ($ZnSO_4.7H_2O$)	12.32	12.71	16.85	17.49	42.26	42.09
2.0% ZEU (ZnO)	11.92	12.26	16.38	16.91	42.13	42.06
5.0 kg Zn/ha ($ZnSO_4.7H_2O$)	11.91	12.23	16.25	16.77	42.30	42.18
5.0 kg Zn/ha (ZnO)	11.61	11.93	15.86	16.36	42.29	42.20
CMCU**	11.25	11.49	15.68	16.16	41.80	41.58
SEm±	0.07	0.13	0.25	0.26	0.52	0.62
LSD (P=0.05)	0.21	0.38	0.73	0.73	NS	NS

*ZEU, Zinc-enriched u rea; CMCU**, Coating material coated urea

Table 2 Effect of dual-purpose summer legumes and zinc fertilization on N economy of aromatic hybrid rice-wheat cropping system

Treatment	Total N input (kg/ha)		Total N uptake (kg/ha)		Balance (kg/ha)	
	2007-08	2008-09	2007-08	2008-09	2007-08	2008-09
Dual-purpose summer legumes						
Summer fallow	128.6	128.9	217.0	209.5	–88.5	–80.9
Mungbean	201.0	208.5	263.8	278.9	–62.8	–70.4
Cowpea	226.5	235.1	264.2	281.2	–37.7	–46.1
SEm±			1.6	0.3	1.6	0.3
LSD (P=0.05)			6.2	1.2	6.2	1.2
Zinc fertilization						
Absolute control (no N and no Zn)	56.8	62.1	177.5	169.7	–120.7	–107.6
Control (only N)	206.8	212.1	243.7	252.8	–36.9	–40.7
2.0% ZEU* ($ZnSO_4.7H_2O$)	206.8	212.1	281.7	295.8	–74.9	–83.7
2.0% ZEU (ZnO)	206.8	212.1	270.4	282.6	–63.6	–70.4
5.0 kg Zn/ha ($ZnSO_4.7H_2O$)	206.8	212.1	264.9	276.6	–58.1	–64.5
5.0 kg Zn/ha (ZnO)	206.8	212.1	255.2	266.4	–48.4	–54.2
CMCU**	206.8	212.1	245.1	251.7	–38.3	–39.5
SEm±			1.9	1.7	1.9	1.7
LSD (P=0.05)			5.5	4.7	5.5	4.7

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

in all treatments during 2008-09 compared to 2007-08 except absolute control which shows concern of nutrient mining in the rice-wheat system over the years.

This might be due to application of legume residue resulted in increased microbial activity and organic acids secretion, phytosiderophores and hormones into the soil, which in turn, made unavailable pool of the nutrients in the available form. This resulted in more N uptake as well as least negative balance of N. This negative balance of the N in all the treatments was also due to increase in the system productivity by application of Zn which is a one of the most limiting factor for declining productivity of this system under Zn stress condition and thus there was more uptake of N which resulted into negative balance. So, it can be said that there is need of balance fertilization of macro and micro nutrient for realization of higher productivity and nutrient balance in the soil.

The system productivity has positive correlation with the total nitrogen uptake in aromatic hybrid rice-wheat system (Fig 1). It was slightly more positively related to

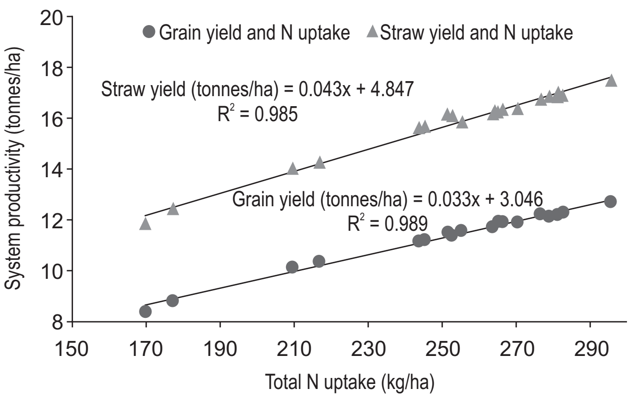

Fig 1 Relationships between aromatic hybrid rice-wheat system productivity and total nitrogen uptake.

grain compared to straw productivity which shows that for effective grain filling nitrogen must be taken care in bettering source-sink relationship.

Zinc economy

Between two dual-purpose summer legumes, Zn input was highest in the cowpea residue incorporated plot as compared to mungbean and summer fallow but among Zn fertilization treatments, Zn input was same for all treatments except absolute control, control and CMCU (Table 3). The significantly higher total Zn uptake (grain + straw) of aromatic hybrid rice-wheat cropping system was recorded when it was grown after preceding cowpea residue incorporation. The total Zn uptake increased significantly with application of 2.0% ZEU ($ZnSO_4.7H_2O$) which was the highest compared to rest of the Zn treatments applied to aromatic hybrid rice.

Although, summer fallow resulted in highest positive (+) Zn balance and minimum was recorded in mungbean residue incorporated plots. This was due to significantly lesser grain and straw system productivity in summer fallow over legume incorporation and resulted in lesser uptake by the crops as uptake is directly related to biomass produced. Among Zn treatments applied to aromatic hybrid rice; absolute control, control (only N) and CMCU recorded negative (-) Zn balance during both the years but it was more negative in 2008-09 compared to 2007-08 in these treatments except absolute control. However, the highest positive balance of Zn was recorded with 5.0 kg Zn/ha (ZnO) as soil application due to lesser biomass produced in system over other three Zn treatments. The highest negative balance of Zn was recorded in CMCU due to more yield compared to control where only N was applied and absolute control having no fertilization at all.

As there was less productivity and also lesser concentrations of Zn with 5.0 kg Zn/ha (ZnO) however, there was the same input of Zn, which led to lesser uptake of total Zn in this treatment, so there was more positive (+) balance of Zn. Shivay *et al.* (2008a) also reported significant improvement in total Zn uptake with the application of Zn-coated fertilizers and also higher buildup of Zn in soil with Zn-enriched urea under rice-wheat cropping system. Also the rice recorded nearly 4.0-4.7 times more Zn uptake than wheat, which could explain why zinc deficiency was first detected in rice (Nene 1966).

A positive correlation of the system productivity was found with the total zinc uptake in aromatic hybrid rice-wheat system (Fig 2). It was found to be more positively related to grain compared to straw productivity. Thus, zinc application and its uptake is crucial for enhancing the productivity of aromatic hybrid rice–wheat cropping system.

Table 3 Effect of dual-purpose summer legumes and zinc fertilization on Zn economy of aromatic hybrid rice-wheat cropping system

Treatment	Total Zn input (g/ha)		Total Zn uptake (g/ha)		Balance (g/ha)	
	2007-08	2008-09	2007-08	2008-09	2007-08	2008-09
Dual-purpose summer legumes						
Summer fallow	2 857	2 857	2 178.9	2 104.8	678	752
Mungbean	3 056	3 078	2 563.9	2 700.3	492	378
Cowpea	3 159	3 185	2 592.0	2 759.2	567	426
SEm±			16.2	20.1	16	20
LSD (*P*=0.05)			63.8	79.1	64	79
Zinc fertilization						
Absolute control (no N and no Zn)	167	183	1 643.1	1 575.5	–1 476	–1 392
Control (only N)	167	183	2 304.2	2 353.4	–2 137	–2 170
2.0% ZEU* ($ZnSO_4.7H_2O$)	5 167	5 183	2 995.3	3 139.8	2 171	2 043
2.0% ZEU (ZnO)	5 167	5 183	2 705.5	2 851.9	2 461	2 331
5.0 kg Zn/ha ($ZnSO_4.7H_2O$)	5 167	5 183	2 667.6	2 785.7	2 499	2 397
5.0 kg Zn/ha (ZnO)	5 167	5 183	2 470.7	2 581.6	2 696	2 601
CMCU**	167	183	2 328.2	2 361.9	–2 161	–2 179
SEm±			37.2	35.8	37	36
LSD (*P*=0.05)			106.6	102.8	107	103

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

Table 4 Effect of dual-purpose summer legumes and zinc fertilization on efficiencies of N in aromatic hybrid rice-wheat cropping system

Treatments	Partial factor productivity (kg grain/kg N)		Agronomic efficiency (kg grain increased/ kg N applied)		Crop recovery efficiency (%)		Physiological efficiency (kg grain/kg N uptake)		N harvest index (%)	
	2007-08	2008-09	2007-08	2008-09	2007-08	2008-09	2007-08	2008-09	2007-08	2008-09
Dual-purpose summer legumes										
Summer fallow	71.7	70.3	18.5	20.0	50.1	53.6	58.0	57.2	65.6	65.7
Mungbean	81.1	84.7	19.4	26.1	58.0	74.2	51.4	55.3	64.7	64.3
Cowpea	81.1	85.1	19.2	26.2	57.3	74.7	53.0	55.8	64.3	63.9
SEm±	0.13	0.14	0.29	1.26	1.56	1.50	1.97	1.18	0.3	0.3
LSD (*P*=0.05)	0.50	0.56	NS	4.93	6.13	5.87	NS	NS	NS	NS
Zinc fertilization										
Absolute control (no N and no Zn)									64.9	64.8
Control (only N)	74.5	76.1	15.5	20.2	44.1	55.4	55.5	57.7	64.6	64.4
2.0% ZEU* ($ZnSO_4.7H_2O$)	82.1	84.7	23.2	28.8	69.5	84.1	51.8	53.4	64.9	64.6
2.0% ZEU (ZnO)	79.4	81.7	20.5	25.8	62.0	75.2	51.6	53.6	64.7	64.6
5.0 kg Zn/ha ($ZnSO_4.7H_2O$)	79.4	81.5	20.4	25.6	58.3	71.3	54.4	55.9	65.0	64.7
5.0 kg Zn/ha (ZnO)	77.4	79.5	18.5	23.6	51.8	64.4	55.1	56.2	65.2	65.0
CMCU**	75.0	76.6	16.1	20.7	45.1	54.6	56.3	59.6	64.7	64.4
SEm±	0.54	0.94	0.54	0.94	1.35	1.15	1.62	1.02	0.5	0.6
LSD (*P* = 0.05)	1.54	2.70	1.54	2.70	3.86	3.31	NS	2.93	NS	NS

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

NUTRIENT-USE EFFICIENCIES IN RICE-WHEAT CROPPING SYSTEM

Nitrogen-use efficiencies

The highest partial factor productivity of applied N (PFP_N) during both years and agronomic efficiency and crop recovery efficiency of N during 2008-09 of aromatic hybrid rice-wheat cropping system was recorded, when grown after cowpea residue incorporation which was significantly superior to summer fallow and remained statistically on par to mungbean residue incorporation (Table 4). Crop recovery efficiency during 2007-08 was significantly higher in mungbean residue incorporation compared to summer fallow but remained statistically on par with cowpea residue incorporation. In general, all these estimated values were higher during 2008-09 as compared to 2007-08 due to higher productivity. Similar results were also reported by Kumar *et al.* (2009).

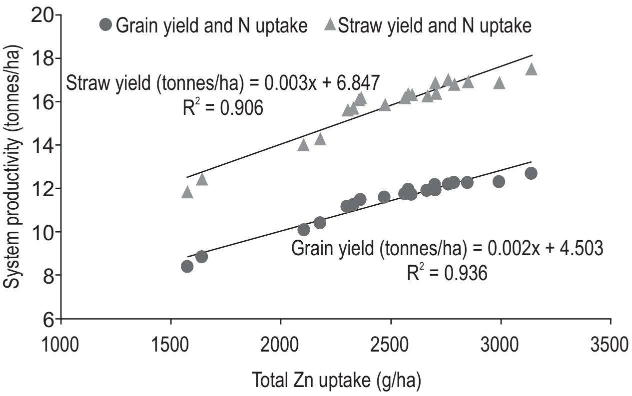

Fig 2 Relationships between aromatic hybrid rice-wheat system productivity and total zinc uptake.

Recovery of applied N varied from 44 to 70% in 2007-08 and 55 to 84% during 2008-09 of the study in rice-wheat cropping system. Application of 2.0% ZEU ($ZnSO_4.7H_2O$) recorded significantly higher N use indices over absolute control, control and all other Zn fertilization treatments. The physiological efficiency of aromatic hybrid rice-wheat cropping system was significantly higher in 2008-09 with CMCU treatment over rest of the Zn treatments applied to aromatic hybrid rice. The percentage increase in agronomic efficiency with 2.0% ZEU ($ZnSO_4.7H_2O$) were in the order of 49.7, 13.2, 13.7, 25.4 and 44.1 over control, 2.0% ZEU (ZnO), 5.0 kg Zn/ha ($ZnSO_4.7H_2O$), 5.0 kg Zn/ha (ZnO) and CMCU during 2007-08, respectively. The percentage increase in crop recovery efficiency (%) with 2.0% ZEU ($ZnSO_4.7H_2O$) were in the order of 57.6 and 51.8; 12.1 and 11.8; 19.2 and 18.0; 34.2 and 30.6; 54.1 and 54.0 over control, 2.0% ZEU (ZnO), 5.0 kg Zn/ha ($ZnSO_4.7H_2O$), 5.0 kg Zn/ha (ZnO) and CMCU during 2007-08 and 2008-09, respectively. There was no significant effect of preceding dual-purpose summer legumes as well as zinc fertilization on N harvest index of aromatic hybrid rice-wheat cropping system.

Table 5 Effect of dual-purpose summer legumes and zinc fertilization on efficiencies of Zn in aromatic hybrid rice-wheat cropping system

Treatments	Partial factor productivity (kg grain/kg Zn)		Agronomic efficiency (kg grain increased/ kg Zn applied)		Zinc apparent recovery (%)		Physiological efficiency (kg grain/kg Zn uptake)		Zn harvest index (%)	
	2007-08	2008-09	2007-08	2008-09	2007-08	2008-09	2007-08	2008-09	2007-08	2008-09
Dual-purpose summer legumes										
Summer fallow	2198	2170	146.3	188.5	7.1	8.0	16528	14333	10.6	10.7
Mungbean	2484	2595	164.0	168.7	8.7	11.8	13397	11646	11.0	11.1
Cowpea	2481	2602	150.5	159.8	8.5	9.4	11713	9275	11.0	11.1
SEm±	14.2	11.7	9.25	5.87	0.63	0.70	1061.9	460.7	0.08	0.06
LSD (P=0.05)	55.7	45.9	NS	NS	NS	2.77	NS	1808.9	0.32	0.24
Zinc fertilization										
Absolute control (no N and no Zn)									10.4	10.4
Control (only N)									10.5	10.5
2.0% ZEU* ($ZnSO_4.7H_2O$)	2464	2541	230.0	257.2	13.8	15.7	12872	11191	11.3	11.5
2.0% ZEU (ZnO)	2383	2452	149.1	169.1	8.1	10.0	14744	12738	10.9	11.0
5.0 kg Zn/ha ($ZnSO_4.7H_2O$)	2381	2445	147.1	161.0	7.3	8.6	12320	11465	11.4	11.6
5.0 kg Zn/ha (ZnO)	2322	2386	88.2	101.9	3.3	4.6	15582	11612	11.1	11.3
CMCU**									10.4	10.6
SEm±	13.0	29.7	6.17	9.63	0.51	0.66	738.6	839.2	0.20	0.26
LSD (P=0.05)	37.5	85.9	17.82	27.82	1.47	1.91	2133.2	NS	0.58	0.74

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

The highest physiological use efficiency of N was recorded with CMCU treatment and it might be due to lesser N uptake and higher productivity of aromatic hybrid rice-wheat cropping system as compared to other treatments. The positive effect of applied Zn on productivity of aromatic hybrid rice-wheat cropping system caused an increase in agronomic efficiency of applied N. The synergistic effects of Zn on N uptake might have caused a variation in crop recovery efficiency of N under different treatments. The main cause of low recovery efficiency of N is due to N loss through several mechanisms (Prasad 2005). The slow release of nitrogen in zinc coated fertilizer may cause less losses of the fertilized N in the environment by leaching, denitrification, etc. This might have helped in more N availability for crop utilization and resulted in higher productivity and efficiencies of the applied fertilizer nitrogen.

Zinc-use efficiencies

The preceding dual-purpose summer legumes had significant effect on partial factor productivity (kg grain/kg Zn) and harvest index of Zn in aromatic hybrid rice-wheat cropping system during both the years of field study and Zn apparent recovery (%) during 2008-09 only (Table 5). All these estimated values of applied Zn were significantly higher in cowpea residue incorporated plot which was on par to mungbean residue incorporated plot during both the years of study but was significantly superior compared to summer fallow. However, physiological efficiency was significantly higher in summer fallow over dual-purpose legumes in 2008-09.

Zn fertilization had significant effect on partial factor productivity (kg grain/kg Zn), agronomic efficiency and crop recovery efficiency of aromatic hybrid rice-wheat cropping system which was significantly higher with 2.0% ZEU ($ZnSO_4.7H_2O$) over all the remaining Zn fertilization treatments. It might be due to more and continuous supply of Zn through ZEU to aromatic hybrid rice which resulted in higher productivity and increased recovery of Zn as compared to soil application in aromatic hybrid rice-wheat cropping system. But the physiological efficiency was higher in 5.0 kg Zn/ha (ZnO) during 2007-08 over rest of the Zn treatments under study. Zn harvest index was significantly higher with 5.0 kg Zn/ha ($ZnSO_4.7H_2O$) and all the Zn fertilization treatments were on par to 2.0% ZEU ($ZnSO_4.7H_2O$) in terms of Zn harvest index however all these treatments were better than absolute control and control. The percentage increase in agronomic efficiency of aromatic hybrid rice-wheat cropping system with 2.0% ZEU ($ZnSO_4.7H_2O$) were in the order of 54.3, 56.4 and 160.8 over 2.0% ZEU (ZnO), 5.0 kg Zn/ha ($ZnSO_4.7H_2O$) and 5.0 kg Zn/ha (ZnO) during 2007-08, respectively. The percentage increase in Zn apparent recovery of aromatic hybrid rice-wheat cropping system with 2.0% ZEU

($ZnSO_4.7H_2O$) were in the order of 70.4, 89.0 and 318.2 over 2% ZEU (ZnO), 5.0 kg Zn/ha ($ZnSO_4.7H_2O$) and 5.0 kg Zn/ha (ZnO) during 2007-08, respectively. Almost same trends were also followed in 2008-09.

Recovery efficiency of applied Zn is low because its rapid adsorption over soil organic matter and clay minerals (Hazra and Mandal 1995) and its subsequent slow desorption (Mandal *et al.* 2000). As compared to N-indices very high values of Zn-indices were obtained due to very small amount of Zn needed for rice growth and grain production as compared to N (Prasad *et al.* 2000).

Economics of rice-wheat cropping system

The highest gross returns during both the years and net returns and B:C ratio during 2007-08 were recorded when dual-purpose summer legumes-aromatic hybrid rice-wheat cropping system was grown after the incorporation of cowpea residue, while it was minimum when aromatic hybrid rice was grown after summer fallow treatment in both the years of experimentation (Table 6). During 2008-09 the highest net returns and B:C ratio was recorded when incorporation of mungbean residue was done and it remained statistically on par with cowpea residue incorporation. It was due to more system productivity in legumes incorporated plots compared to summer fallow in rice-wheat cropping system. The dual-purpose summer legume incorporation in rice-wheat system gave higher net returns by 29 to 34% in 2007-08 and 42 to 45% during 2008-09 over summer fallow with B:C ratio up to 3.01. Tripathi and Singh (2007) also reported almost similar findings as is accordance to present study.

Zn fertilization in aromatic hybrid rice had significant effect on gross returns, net returns and B:C ratio of dual-purpose summer legumes-aromatic hybrid rice-wheat cropping system. The gross returns, net returns and B:C ratio recorded significantly higher with 2.0% ZEU ($ZnSO_4.7H_2O$) during both the years of study and the lowest with absolute control. The percentage increases in net returns with 2.0% ZEU ($ZnSO_4.7H_2O$) were in the order of 44.4 and 56.9; 11.6 and 12.2; 4.1 and 4.3; 4.3 and 4.7; 7.7 and 7.8; 10.9 and 11.5 over absolute control, control, 2.0% ZEU (ZnO), 5.0 kg Zn/ha ($ZnSO_4.7H_2O$), 5.0 kg Zn/ha (ZnO) and CMCU during 2007-08 and 2008-09, respectively. The similar trends were also recorded with regard to gross returns of dual-purpose summer legumes-aromatic hybrid rice-wheat cropping system in both the years of experimentation. It was due to more system productivity in Zn-enriched urea treated plots compared to summer fallow in rice-wheat cropping system which resulted into more income over rest of the treatments under investigation. Shivay *et al.* (2008b) also reported significant improvement in the returns and B:C ratio of rice-wheat cropping system due to application of Zn-enriched urea.

Zinc sulphate is water soluble and therefore readily available, while ZnO is sparingly soluble and was not readily available to crop plants. Thus, Zn from zinc oxide-coated urea will also make Zn available to rice but released Zn may interact with water and CO_2 in soil solution to form $Zn(OH)_2$ and $ZnCO_3$ which have lesser solubility than ZnO. The results of the present study show that Zn availability from ZnO-coated ureas to aromatic hybrid rice-wheat cropping system is much slower and it becomes available only at later growth stages and thus remained more in straw than in grain. These results are similar with the findings of Shivay *et al.* (2008a).

Based on the two year study it was concluded that the

Table 6 Effect of dual-purpose summer legumes and zinc fertilization on economics of dual-purpose summer legumes–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	119 831	128 898	81511	89905	2.05	2.22
Mungbean	154 757	183 612	111014	139123	2.44	3.01
Cowpea	161 014	186 852	116313	141405	2.51	3.00
SEm±	729	665	729	665	0.02	0.01
LSD (*P*=0.05)	2 861	2 612	2861	2312	0.06	0.06
Zinc fertilization						
Absolute control (no N and no Zn)	117 699	127 560	78722	87873	1.93	2.11
Control (only N)	144 288	166 123	101827	122938	2.30	2.72
2.0% ZEU* ($ZnSO_4.7H_2O$)	156 655	181 599	113678	137898	2.54	3.02
2.0% ZEU (ZnO)	152 156	175 968	109178	132267	2.44	2.90
5.0 kg Zn/ha ($ZnSO_4.7H_2O$)	151 976	1,75,411	109023	131735	2.44	2.89
5.0 kg Zn/ha (ZnO)	148 526	171 604	105573	127927	2.36	2.80
CMCU**	1,45,107	1,66,913	102621	123704	2.32	2.74
SEm±	588	996	588	996	0.01	0.02
LSD (*P*=0.05)	1,688	2,857	1688	2857	0.04	0.06

*ZEU, Zinc-enriched urea; CMCU**, Coating material coated urea highest rice-wheat cropping system productivity, total N and Zn uptake, gross returns, net returns and B:C ratio was recorded in the plots of residue incorporation of either cowpea or mungbean. Among Zn treatments, application of 2.0% ZEU ($ZnSO_4.7H_2O$) recorded the highest productivity, N and Zn uptake, gross returns, net returns and B:C ratio. N and Zn balance, partial factor productivity, agronomic efficiency, apparent recovery and physiological efficiency of applied Zn and N in aromatic hybrid rice-wheat cropping system was increased with incorporation of either mungbean or cowpea residue and 2% ZEU.

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