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Agronomic evaluation of zinc-enriched urea formulations in scented rice (*Oryza sativa*)*

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Sustaining supply of deficient micronutrients along with primary macronutrients (NPK) in appropriate amount and right proportion is a key to maximize productivity gains from macronutrients. Of the eight micronutrients, maximum attention has been focused on zinc (Zn). Apparent reason for this tilt is the overwhelming dominance of Zn deficiency in Indian soils and crops compared to other nutrients (Takkar *et al.* 1997 and Rattan *et al.* 1997). The zinc deficiency is more widespread in the rice (*Oryza sativa.*)– wheat (*Triticum aestivum* L. emend. Fiori & Paol.) cropping system belt in northern India. The recommendation for zinc which is generally marketed as zinc sulphate heptahydrate ($ZnSO_4.7H_2O$) vary from 10 to 25 kg/ha/season, depending upon the crop, environment and soil conditions (Prasad 2005). One of the major problems the farmers are facing in this context is the non-availability of good quality zinc sulphate. In such a situation, a good quality zinc-enriched urea (ZEU), manufactured by a fertilizer company will be the ideal one and the Government of India's Fertilizer Control Order has also made the provision for manufacturing and coating of up to 2% zinc-enriched urea. Of late, some zinc-enriched urea has become available in the Indian market, but no experimental data are available on its evaluation in field crops. Therefore, considering the above facts, a field experiment was conducted to find out the response of scented rice to zinc-enriched urea formulations, and also to determine the optimum concentration of zinc enrichment of urea for enhanced productivity and zinc uptake in scented rice.

The field experiment was conducted at the Research Farm of Indian Agricultural Research Institute, New Delhi (77°12' E and 28°40' N; 228.4 m above mean sea level) during rainy (*kharif)* season of 2006. The soil was sandy clay loam, alkaline in reaction (*p*H 8.2), having 0.53% organic carbon, 0.05% total N, 14.5 kg/ha available P, 247 kg/ha available K and 0.68 mg/kg DTPA-extractable Zn in 0–15 cm soil depth at the start of the experiment. The critical level of DTPA extractable Zn for rice grown on alluvial soils in the rice–wheat belt of north India varies from 0.38 to 0.90 mg/kg soil (Takkar *et al.* 1997). Thus the soil had quite low levels of available zinc. There were 12 treatments consisting of eight combinations of two zinc-enrichment materials ($ZnSO_4$ and ZnO) and four levels of Zn-enrichment (0.5, 1.0, 1.5 and 2.0% w/w of prilled urea) plus a no Zn control (only N), absolute control (no zinc, no N), $ZnSO_4$ 5 kg Zn/ha (soil application) + prilled urea and 0.2% $ZnSO_4$ foliar spray + prilled urea. Zinc oxide and zinc sulphate monohydrate contained 80% and 33% Zn, respectively. Foliar spray of 0.2% zinc sulphate monohydrate (33% Zn) was done twice at panicle emergence and 10 days after panicle emergence. The treatments (T_{12}) were replicated thrice in a randomized block design. All plots, except absolute control (no Zn, no N), received 120 kg N/ha as prilled urea. The experimental field was disk ploughed twice, puddled thrice with a puddler in standing water and leveled. At final puddling, 26 kg P/ha as single superphosphate and 33 kg K/ha as murite of potash was broadcast. Nitrogen at 120 kg N/ha as prilled urea or Zn-enriched urea was applied in two equal splits, half 10 days after transplanting and the other half at panicle initiation (40 days after transplanting). When applied at the site, Zn-enriched urea supplied 1.3, 2.6, 3.9 and 5.2 kg. Zn/ha for the 0.5, 1.0, 1.5 and 2.0% coatings, respectively. To make up for the short fall of N in Zn-enriched ureas, calculated amounts of additional N as prilled urea were added in plots receiving Zn-enriched ureas. Two to three 25-day-old seedlings of 'Pusa Sugandh' 5 basmati (scented) rice were transplanted on hills spaced at 20 cm×10 cm in the second week of July 2006. Standing water (5–8 cm) in the plots was maintained until grain-filling stage. Rice was harvested in the third week of October. At harvest, grain and straw yield was recorded for

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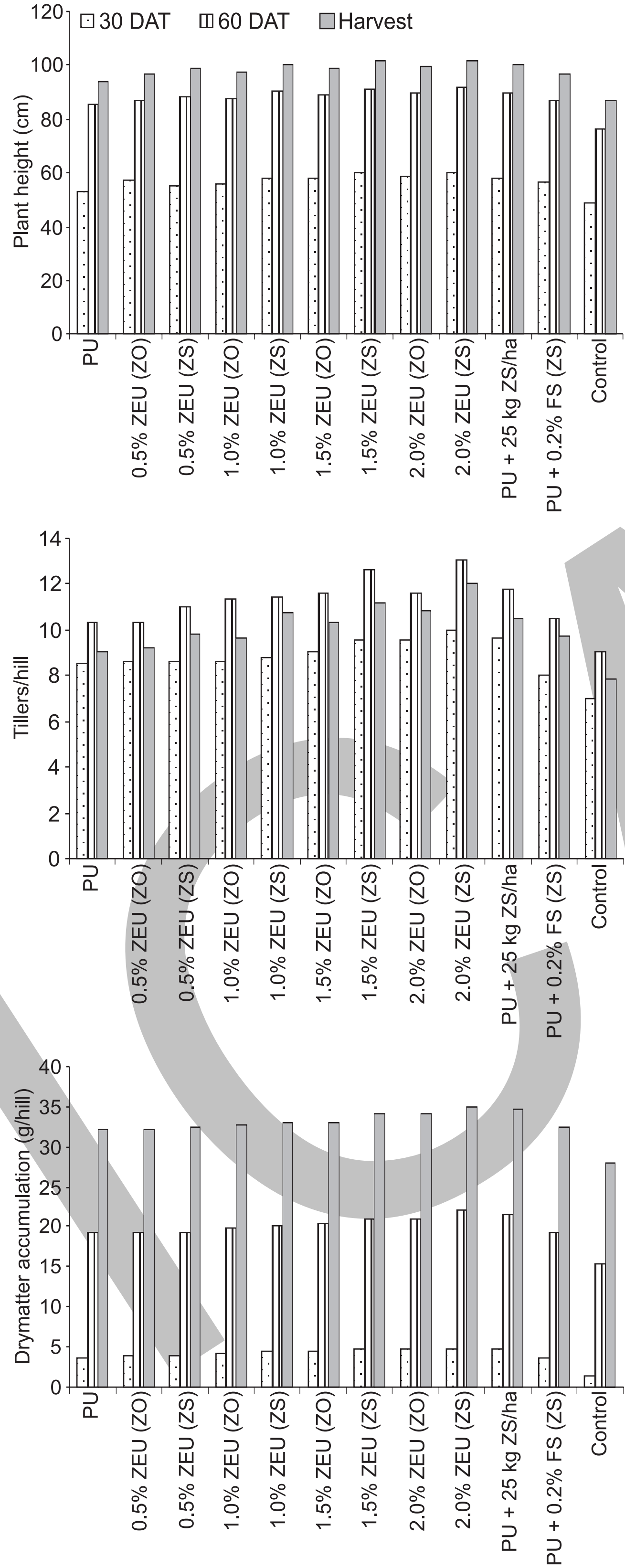

Fig 1 Effect of zinc-enriched urea formulations on growth of scented rice

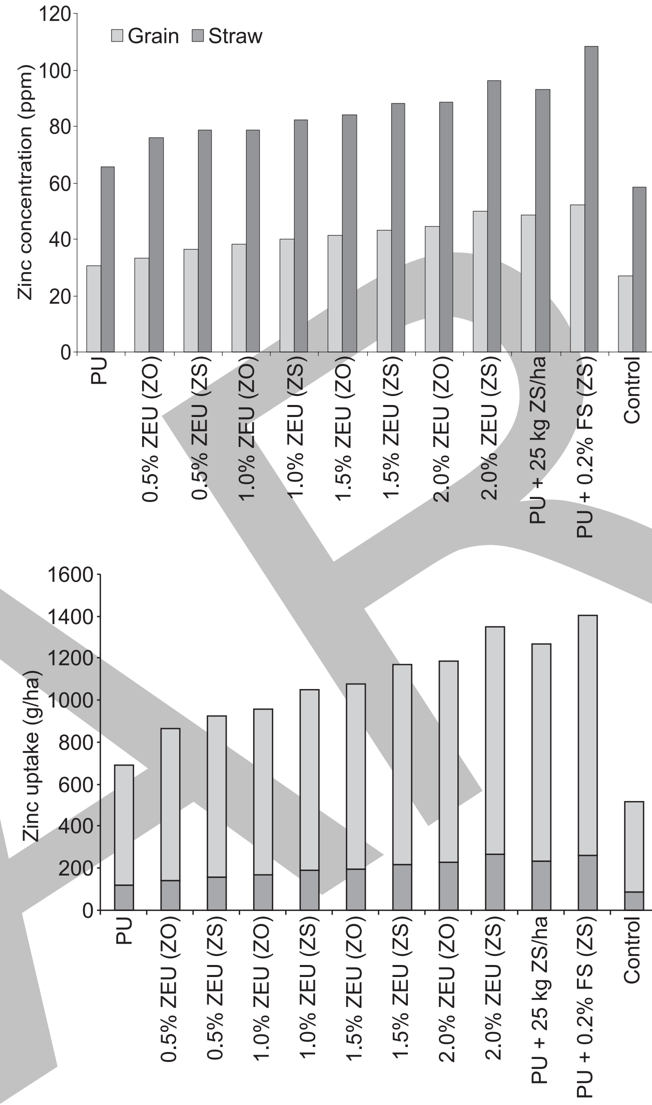

Fig 2 Effect of zinc-enriched urea formulations on zinc concentration and uptake (g/ha) by grain and straw of scented rice

each plot of the experiment, and samples of grain and straw were drawn from each plot for the chemical analysis for N and Zn concentrations. After proper cleaning and winnowing the grain weight of each plot at 14% moisture was recorded. 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). Different nitrogen-use efficiencies (NUE), such as agronomic nitrogen-use efficiency (ANUE), apparent nitrogen recovery (ANR) and physiological efficiency of applied nitrogen (PEN), were worked out (Bandyopadhyay and Sarkar 2006).

Zinc-enriched urea formulations increased the plant height significantly over control and prilled urea at all the three stages, i e 30 days after transplanting, 60 days after transplanting and harvest (Fig 1). At harvest, the highest number of tillers/hill was recorded with 2.0% zinc-enriched urea (zinc sulphate), which was significantly higher than control, prilled urea alone, 0.5% zinc-enriched urea (zinc oxide), 0.5% zinc-enriched urea (zinc sulphate), 1.0% zinc-enriched urea (zinc oxide), 1.0% zinc-enriched urea (zinc sulphate) and 1.5% zinc-enriched urea (zinc oxide). At all the three stages, the highest dry matter was accumulated with 2.0% zinc-enriched urea (zinc sulphate), being at par with 1.0% zinc-enriched urea (zinc sulphate), 2.0% zinc-enriched urea(zinc oxide) and soil application of zinc sulphate @ 25 kg/ha, and significantly higher to prilled urea alone and absolute control (Fig 1). The highest content of chlorophyll (mg/g) in flag leaf at panicle initiation was recorded with 2.0% zinc-enriched urea (zinc oxide), which was significantly higher to all the other zinc-enriched ureas, soil applied zinc (25 kg zinc sulphate/ha) and foliar spray of 0.2% zinc sulphate (Table 1). The highest number of fertile tillers/hill were obtained with 2.0% zinc-enriched urea (zinc sulphate), being at par with 1.5% zinc-enriched urea (zinc sulphate) and significantly higher to all the other zinc-enriched urea formulations, soil applied zinc sulphate (25 kg/ha) and foliar spray of 0.2% zinc sulphate (Table 1). The highest panicle weight was observed with 2.0% zinc-enriched urea (zinc sulphate), which was at par with all the zinc-enriched urea formulations tested, soil applied zinc sulphate 25 kg/ha and foliar spray of 0.2% zinc sulphate. Also, the highest number of filled grains/panicle were recorded with 2.0% zinc-enriched urea (zinc sulphate), which were at par with 2.0% zinc-enriched urea (zinc oxide), 1.5% zinc-enriched urea (zinc oxide or zinc sulphate), 1.0% zinc-enriched urea (zinc oxide or zinc sulphate), 0.5% zinc-enriched urea (zinc sulphate), soil applied zinc sulphate 25 kg/ha, foliar spray of 0.2% zinc sulphate and significantly greater to 0.5% zinc-enriched urea (zinc oxide) and prilled urea alone. The highest grain yield was obtained with 2.0% zinc-enriched urea (zinc sulphate), which was at par with 2.0% zinc-enriched urea (zinc oxide), 1.5% zinc-enriched urea (zinc sulphate) and soil applied zinc sulphate @ 25 kg/ha, whereas it was significantly higher to all the other treatments including foliar spray of 0.2% zinc sulphate (Table 2). Zinc enrichment of prilled urea (PU) at 0.5% Zn (through zinc sulphate) and at higher levels (1–2%) increased the grain yield significantly over prilled urea alone. The increase in grain yield in zinc-enriched urea treatments over prilled urea ranged from 7.7% (0.5% zinc-enriched urea–zinc oxide) to 35.9% (2.0% zinc-enriched urea–zinc sulphate). Foliar spray of 0.2% zinc sulphate was quite beneficial over prilled urea alone, 0.5% zinc-enriched urea (zinc oxide or zinc sulphate) and 1.0% zinc-enriched urea (zinc oxide), with respect to grain yield. In general, zinc sulphate-enriched urea was a better source than zinc oxide-enriched urea at a same level of zinc enrichment. A number of studies have been made to compare the relative efficiency of different sources of zinc and some have indicated that water-soluble zinc sulphate was a superior source for rice (Nayyar *et al.* 1990; Takkar *et al.* 1989). Zinc fertilizer source, averaged over application times, significantly affected grain yield at all sites with zinc fertilization increasing yields by 12 to 180% compared with the unfertilized control (Slaton *et al.* 2005).

N concentration in grain and straw ranged from 1.00–1.28 and 0.53–0.72%, respectively (Table 2). The highest N concentration both in grain and straw was observed with 2.0% zinc-enriched urea (zinc sulphate), which was at par with 2%

Table 1 Effect of zinc-enriched urea formulations on LAI, chlorophyll content in flag leaf and yield attributes of scented rice

Treatment	Amount of zinc (kg/ha) applied	Leaf area index (LAI)		Chlorophyll content in flag leaf (mg/g)		Yield attributes					
		30 DAT	60 DAT	PE	7 DAPE	Effective tillers/ hill	Panicle weight (g)	Panicle length (cm)	Filled grains/ panicle	Grain (g) weight/ panicle	1000-grain weight (g)
Prilled urea (PU)	0	3.2	6.0	5.0	4.6	7.6	4.6	24.2	97.6	2.6	26.3
0.5% ZEU (ZO)	1.3	3.2	6.2	5.4	4.9	8.2	4.7	24.6	101.3	2.7	26.9
0.5% ZEU (ZS)	1.3	3.4	6.3	5.8	5.3	8.8	4.7	25.3	106.6	2.7	27.7
1.0% ZEU (ZO)	2.6	3.4	6.4	6.0	5.5	8.6	4.8	25.0	108.0	2.8	27.1
1.0% ZEU (ZS)	2.6	3.6	6.8	6.6	6.1	9.7	4.9	26.0	114.3	2.9	28.3
1.5% ZEU (ZO)	3.9	3.6	7.0	6.4	5.9	9.3	4.9	25.5	111.3	2.9	27.4
1.5% ZEU (ZS)	3.9	3.8	7.3	6.8	6.3	10.2	5.1	26.8	120.6	3.1	28.9
2.0% ZEU (ZO)	5.2	3.8	7.2	8.6	6.1	9.8	5.0	26.0	117.6	3.0	28.0
2.0% ZEU (ZS)	5.2	4.0	7.5	7.0	6.5	11.0	5.2	27.7	125.6	3.2	29.3
PU + 25 kg ZS/ha soil application	5.3	3.9	7.4	7.0	6.5	9.5	5.1	26.5	118.3	3.1	28.8
PU + 0.2% FS (ZS)	0.53	3.2	6.1	5.1	4.6	8.7	4.8	25.2	108.6	2.8	27.8
Control	0	1.5	4.5	3.2	3.0	6.3	3.2	21.0	73.6	2.2	21.4
LSD (P=0.05)		0.5	0.3	1.6	1.6	1.1	1.2	1.2	22.3	0.1	3.9

ZEU, Zinc-enriched urea; ZO, zinc oxide; ZS, zinc sulphate; FS, foliar spray (at panicle emergence, 10 days after panicle emergence); DAT, days after transplanting; PE, panicle emergence; DAPE, days after panicle emergence zinc-enriched urea (zinc oxide), 1.5% zinc-enriched urea (zinc sulphate or zinc oxide) and soil applied zinc sulphate 25 kg/ha. Overall, 2.0% zinc-enriched urea (either zinc sulphate or zinc oxide) proved much effective in increasing the N concentration of both grain and straw in rice than other treatments. N uptake in grain, straw and total increased appreciably with the increase in level of zinc enrichment (Table 2). In general, zinc sulphate-enriched urea resulted in more N accumulation in grain, straw and total as compared to the zinc oxide-enriched urea at the same level of zinc enrichment. Agronomic nitrogen-use efficiency with prilled urea, zinc-enriched urea formulations and 0.2% foliar spray (+ prilled urea) at 120 kg N/ha varied from 6.6 to 17.5 kg increase in grain yield/kg applied N (Table 2). The highest agronomic nitrogen-use efficiency was obtained with 2% zinc-enriched urea (zinc sulphate), being at par with foliar spray of 0.2% zinc sulphate, soil applied zinc sulphate 25 kg/ha, 2% zinc-enriched urea (zinc oxide) and 1.5% zinc-enriched urea (zinc sulphate), and significantly higher than the other sources. As regards apparent N recovery (ANR%), except 0.5% zinc-enriched urea (zinc oxide), all the zinc-enriched urea formulations, soil applied zinc sulphate 25 kg/ha and foliar spray of 0.2% zinc sulphate recovered significantly more N than prilled urea alone. The highest apparent N recovery (%) was recorded with 2% zinc-enriched urea (zinc sulphate), which was significantly higher than all other treatments. The apparent N recovery varied from 20.7 to 63.8%. Physiological efficiency of applied N (PEN) varied from 27.2 to 34.2 kg grain/kg N uptake. However, the difference in physiological efficiency of applied N was non-significant due to imposition of different treatments.

Zinc concentration in grain and straw ranged from 26.8 to 52.2 ppm and 58.3 to 108.2 ppm, respectively (Fig 2). The highest zinc concentration (ppm) in grain was recorded in foliar spray of 0.2% zinc sulphate (zinc sulphate), which was at par with soil applied zinc sulphate @ 25 kg/ha and 2.0% zinc-enriched urea (zinc sulphate), and significantly greater to all the other zinc sources, prilled urea alone and the control. All the zinc sources, except 0.5% zinc-enriched urea (zinc oxide), removed significantly higher amounts of Zn in grain over prilled urea alone (Fig 2). The highest zinc uptake in grain was recorded with foliar spray of 0.2% zinc sulphate, which was at par with soil applied zinc sulphate 25 kg/ha and 2% zinc-enriched urea (zinc sulphate or zinc oxide), and significantly greater than rest of the treatments. The zinc sulphate-enriched urea proved to be a better source than zinc oxide-enriched urea with respect to Zn uptake. In general, the water solubility of zinc sulphates and lignosulphonates sources is higher than Zn oxides and Zn oxysulphates sources (Fageria *et al.* 2003). The research data clearly show that tissue Zn concentration and total Zn uptake generally increase as water-soluble Zn in a fertilizer increases. It is also evident from some previous studies that the water solubility of the zinc fertilizer source, the time allowed for vertical movement of the zinc, and the relative placement of zinc fertilizer are all important aspects to consider in Zn fertilization practices. In fact, foliar zinc is usually applied in emergencies to salvage crops when Zn deficiencies appear, and one foliar application is usually not adequate for correcting moderate to severe Zn deficiency (Fageria *et al.* 2002).

SUMMARY

The zinc deficiency is the most widespread micronutrient

Table 2 Effect of zinc-enriched urea formulations on yield, and nitrogen concentration, uptake and efficiency in scented rice

Treatment	Amount of zinc (kg/ha) applied	Grain yield (tonnes/ha)	Straw yield (tonnes/ha)	Nitrogen concentration (%)		Nitrogen uptake (kg/ha)			Agronomic efficiency (kg grain increase/kg N applied)	Apparent N recovery (%)	Physiological efficiency (kg grain increase/kg N uptake)
				Grain	Straw	Grain	Straw	Total			
Prilled urea (PU)	0	3.9	8.8	1.12	0.59	44.3	51.8	96.1	6.6	20.7	32.3
0.5% ZEU (ZO)	1.3	4.2	9.5	1.13	0.61	50.9	58.0	108.9	8.9	28.7	32.9
0.5% ZEU (ZS)	1.3	4.4	9.7	1.15	0.62	50.2	60.4	110.6	10.2	32.8	34.2
1.0% ZEU (ZO)	2.6	4.5	10.0	1.19	0.64	51.9	63.9	115.8	11.0	37.1	29.2
1.0% ZEU (ZS)	2.6	4.7	10.4	1.18	0.65	55.2	68.0	123.2	12.7	43.2	29.4
1.5% ZEU (ZO)	3.9	4.8	10.5	1.20	0.67	57.0	70.5	127.5	13.4	46.9	28.9
1.5% ZEU (ZS)	3.9	5.0	10.8	1.21	0.68	61.2	73.7	134.9	15.7	53.0	29.5
2.0% ZEU (ZO)	5.2	5.1	10.8	1.24	0.70	63.5	75.6	139.1	16.4	56.6	29.1
2.0% ZEU (ZS)	5.2	5.3	11.2	1.28	0.72	67.0	80.8	147.8	17.5	63.8	27.7
PU + 25 kg ZS/ha soil application	5.3	5.2	11.0	1.21	0.68	62.7	74.9	137.6	16.9	55.3	27.2
PU + 0.2% FS (ZS)	0.53	4.9	10.6	1.18	0.64	58.8	67.8	126.6	15.2	46.1	33.1
Control	0	3.2	7.3	1.00	0.53	32.1	39.0	71.1			
LSD (*P*=0.05)		0.4	0.6	0.11	0.05	8.0	9.2	11.6	4.1	10.1	NS

ZEU, Zinc-enriched urea; ZO, zinc oxide; ZS, zinc sulphate; FS, foliar spray (at panicle emergence, 10 days after panicle emergence) disorder in rice. It is suggested that use of zinc-enriched urea may overcome this problem. Hence, an experiment was carried out at Indian Agricultural Research Institute, New Delhi, to find the best zinc-enriched urea formulation. Treatments (12) consisting of eight combinations of two zinc-enrichment materials ($ZnSO_4$ and ZnO) and four levels of Zn-enrichment (0.5, 1.0, 1.5 and 2.0% w/w of prilled urea) plus a no Zn control (only N), absolute control (no zinc, no N), $ZnSO_4$ 5 kg Zn/ha (soil application) + prilled urea and 0.2% $ZnSO_4$ foliar spray + prilled urea were laid out in randomized block design with three replications. It is concluded that zinc sulphate is a better source than zinc oxide for enrichment of prilled urea. Zinc-enriched urea 1.5% (zinc sulphate), in general, proved to be the most effective treatment in realizing higher grain yield and zinc uptake of scented rice.

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