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Effect of zinc on yield, zinc nutrition and zinc use efficiency of lowland rice

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Zinc deficiency in flooded soil is impediment to obtain higher rice yield. Zinc deficiency is corrected by application of suitable zinc fertilizer. The results revealed that rice responded significantly to graded dose of zinc applied. The highest grain (37.53 g pot^{-1}) and straw yield (48.54 g pot^{-1}) was noticed at 5 mg Zn kg^{-1} which was about 100 % and 86% greater than control (no zinc) respectively. Similar effect was noticed on DMP. The highest zinc concentration and uptake in grain and straw and DTPA-Zn at all stages was noticed at 7.5 mg Zn kg^{-1}.The linear regression analysis showed grain zinc concentration and grain Zn uptake caused 89.64 and 89.01% variation in rice yield. Similarly, the linear regression analysis of DTPA-Zn caused 98.31, 96.34 and 93.12% variation in yield of rice at tillering, panicle initiation and harvest stages respectively. The agronomic, physiological and agrophysiological apparent recovery and utilization efficiencies was highest at lower level of zinc application and decreased with Zn doses.

Key words: Rice, zinc nutrition, yield, zinc use efficiency

Introduction

Zinc is one of the most important micronutrient essential for plant growth especially for rice grown under submerged condition. Zinc deficiency is prevalent worldwide in temperate and tropical climates (Fageria *et al*., 2003; Slaton *et al*., 2005). Forty seven percent of Indian soils (Takkar, 1996) and fifty percent of Tamilnadu soils (Anon, 2006) are deficient in zinc. Zinc is a major component and activator of several enzymes involved in metabolic activities (Klug and Rhodes, 1987). Zinc deficiency continues to be one of the key factors in determining rice production in several parts of the country (Chaudhary *et al*., 2007). Rice is the stable food for more than half of the world population and it provides 21% and 15% per capita of dietary energy and

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protein, respectively (Maclean *et al*., 2002). Zinc deficiency in rice has been reported in lowland rice of India (Mandal *et al*., 2000) and Brazil (Fageria *et al*., 2011). Zinc deficiency in plant is noticed when the supply of zinc to the rice plant is inadequate. Among the many factors which influence zinc supply to the plants, pH, concentration of zinc, iron, manganese and phosphorus in soil solution are very important. Brar and Sekon (1976) stated that decrease in availability of zinc in submerged soils are due to the formation of insoluble franklinite ($ZnFe_2O_4$) compound (submerged soil), insoluble ZnS (intense reduced condition), insoluble $ZnCO_3$ (partial pressure of CO_2 coupled with decomposition of OM) and insoluble Zn $(OH)_2$ (alkaline pH).

Zinc deficiency is usually corrected by application of zinc sulfate. Zinc deficiency and response of rice to zinc under flooded condition have been studied by many workers (Gangwar *et al*., 1989; Kausar *et al*., 2004; Naik and Das, 2007; Mollah *et al*., 2009; Fageria *et al*., 2011). Keeping in view the importance of zinc nutrition and its use efficiency in rice, a pot experiment was conducted in two soils to study the effect of zinc fertilization on lowland rice.

Materials and methods

A glass house experiment was conducted during 2010-2011 at Department o Soil Science and Agricultural Chemistry, Faculty of Agriculture, Annamalai University, Tamilnadu, India. The two soils used in the experiment belong to Vertisol (Typic Haplusterts) and Entisol (Typic Ustifluvents). Before imposition of zinc treatments, the soils used in the experiment had the following properties viz., pH 8.02, EC 0.72 dSm^{-1}, organic carbon 6.74 gkg^{-1}, $KMnO_4$-N 283 kg ha^{-1} , Olsen -P 26 kg ha^{-1} , NH_4OAc- K 320 kg ha^{-1} , DTPA-Zn 0.86 $mgkg^{-1}$ and calcium carbonate 2.27% (Vertisol). Similarly soil of Entisol had pH 7.0, EC 0.81dSm^{-1}, organic carbon 8.2 g kg^{-1}, $KMnO_4$-N 298 kg ha^{-1} , Olsen -P 18 kg ha^{-1} , NH_4OAc- K 265 kg ha^{-1} ,DTPA-Zn-0.71 mg kg^{-1} and calcium carbonate 1.64 % . Four rates of zinc were applied to rate different levels of soil Zn. Four rates of zinc were applied to create different levels of soil Zn. These zinc rates of 0. 2.5, 5.0, 7.5 mg Zn kg^{-1} were applied using zinc sulfate. Recommended dose of 150 N kg ha^{-1}, 50 P_2O_5kg ha^{-1} and 50 KCl kg ha^{-1} applied through 1.63 g pot^{-1} urea, 1.56 g pot^{-1} superphosphate and 0.4 g pot^{-1} muriate of potash. The experimental design was performed using Completely Randomized Design (CRD) with four replications. The tested rice variety was ADT 43. Rice nursery was separately raised and twenty one day old rice seedlings were planted in the pots with four seedlings per pot. Each pot was flooded with water to a depth of 5 cm throughout crop growth and drained 3 days before harvest.

Rice plants were removed during tillering, panicle initiation and harvest stages to record DMP, grain and straw yield. It was washed with distilled water repeatedly before drying. Plant and grain samples were powdered after drying and the samples were digested in diacid mixture (HNO_3: $HClO_4$ - 4:1). Zinc concentration in the digested material was estimated in atomic absorption spectrophotometer (AAS) and their uptake was computed by multiplying zinc content (ppm) with DMP. The grain and straw yields were recorded separately. Soil was analyzed for DTPA-Zn (Lindsay and Norwell, 1978). Zinc use efficiency was calculated following the formula proposed by Fageria (2009). Statistical analysis was employed to get meaningful understanding of the treatmental effects.

Results and discussions

Rice yield

Result showed significant increase in DMP at tillering, panicle initiation, grain and straw yield with graded dose of zinc applied over control as seen in Table 1. The maximum DMP of 2.98 g pot^{-1} at tillering and 40.93 g pot^{-1} at panicle initiation was obtained with application of 5 mg Zn kg^{-1} which was about 44 to 60% greater as compared with the treatment that did not receive zinc. This was within the range of recommended dose tested under field condition. Fageria *et al*. (2011) stated that zinc fertilization in lowland rice soil inceptisol also obtained maximum DMP with 5 mg Zn kg^{-1}. The grain and straw yield ranged from 18.70 to 37.53 g pot^{-1} and 26.12 to 48.54 g pot^{-1}, respectively with graded dose of zinc application. The grain yield response due to 2.5, 5.0 and 7.5 mg Zn kg^{-1} over no zinc was 12.47, 18.83 and 18.13 g pot^{-1} respectively. The highest grain yield (37.53 g pot^{-1}) and straw yield (48.54 g pot^{-1}) was noticed at 5 mg Zn kg^{-1} which was about 10% and 86% greater than control (no zinc) respectively. Slaton *et al*. (2005) observed 12 to 180%, while Fageria *et al*. (2011) reported 97% increase in rice yield due to zinc fertilization. Higher yield due to zinc fertilization is attributed to its involvement in many metallic enzyme system, regulatory functions and auxin production (Sachdev *et al*.,1988), enhanced synthesis of carbohydrates and their transport to the site of grain production (Pedda Babu *et al*., 2007). Higher concentration of zinc concentration in the grain maintained by the application of zinc in the rhizosphere with constant supply coupled with more number of productive tillers per hill and higher zinc uptake might have increased the grain yield (Jena *et al*., 2006). The argument on the enhanced rice yield by zinc addition was ably supported by the significant positive correlation observed in the present study between grain yields and DTPA –Zn (0.94** at tillering stage, 0.98** at panicle initiation, 0.97**at harvest stage).Similarly, grain yield with Zn uptake (0.76** at tillering, 0.94** at panicle initiation and 0.92**at harvest stage). Response of lowland rice to zinc addition has been reported widely (Mandal *et al*., 2000; Rahamatullah Khan *et al*., 2007 ; Chaudhary *et al*., 2007 ; Fageria *et al*., 2011)

Table 1. Effect of zinc application on DMP and yield of rice (g pot^{-1})

Zn-Levels (ppm)	DMP (Tillering stage)			DMP (Panicle Initiation)			Grain yield			Straw yield		
	S_1	S_2	Mean	S_1	S_2	Mean	S_1	S_2	Mean	S_1	S_2	Mean
0	1.59	2.54	2.06	20.44	28.62	24.53	13.68	23.73	18.70	18.01	34.23	26.12
2.5	2.28	3.23	2.75	30.00	38.72	34.36	25.68	36.66	31.17	30.67	53.06	41.86
5.0	2.51	3.46	2.98	36.00	45.87	40.93	32.04	43.02	37.53	37.35	59.74	48.54
7.5	2.45	3.17	2.92	35.50	45.35	40.42	31.36	42.34	36.85	37.03	59.42	48.22
Mean	2.20	3.15		30.64	40.42		25.69	36.43		30.76	51.61	
	Zn	S	Zn×S	Zn	S	Zn×S	Zn	S	Zn ×S	Zn	S	Zn ×S
SEd	0.08	0.06	0.12	0.41	0.29	0.58	1.00	1.22	1.14	1.33	1.36	1.43
CD (p=0.05)	0.03	0.02	0.05	0.86	0.60	1.21	2.10	2.54	2.38	2.78	2.83	2.98

Zinc nutrition

The zinc concentration and uptake was significantly influenced by various levels of zinc applied to soil (Fig. 1.). Zinc concentration and uptake showed highest with 7.5 mg Zn kg^{-1}. Chaudhary *et al*. (2007) reported that decrease in zinc concentration with rice growth. The Zn concentration in grain ranged from 22.36 to 46.57 ppm and that of straw 19.74 to 43.95 ppm due to successive increment in zinc addition to soil. The increase in the zinc content in grain and straw might be due to the presence of increased amount of Zn in soil solution by the application of zinc that facilitated greater absorption. Increase in Zn content in grain and straw due to zinc fertilization was reported earlier (Sakal *et al*., 1987; Mollah *et al*., 2009; Fageria *et al*., 2011). The zinc content was higher in grain than in straw. Similar result was reported by Naik and Das (2007).

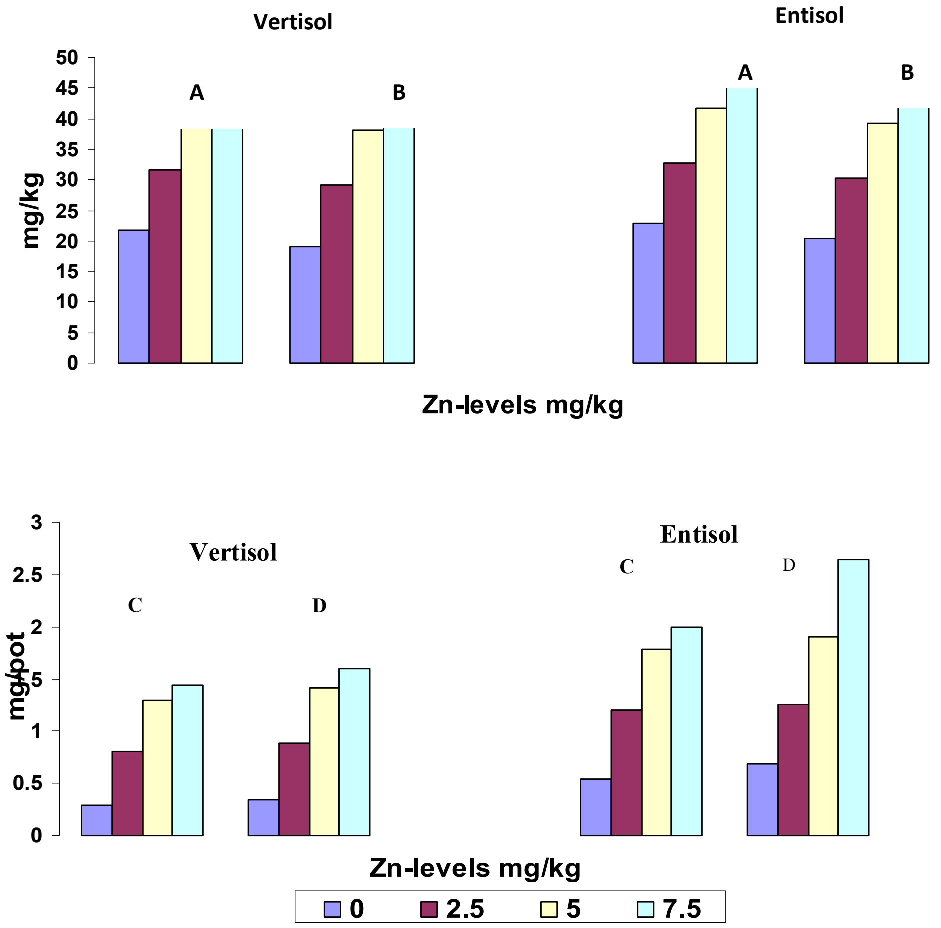


Fig.1. Effect of zinc fertilization on A) grain Zn B) Straw Zn content C) Grain Zn D) Straw Zn uptake

The zinc uptake increased with stages of crop growth. The zinc uptake in grain and straw ranged from 0.41 to 1.71 mg pot^{-1} and 0.51 to 2.12 mg pot^{-1} respectively. The highest grain Zn uptake (1.71 mg/pot) and straw Zn uptake (2.12 mg/pot) was observed at 7.5 mg Zn kg^{-1}. The increase in Zn uptake was due to their increased application could be ascribed to the variation in the availability of applied Zn in the root zone and their role in the growth and development of the plant (Chaudhary and Sinha, 2007). The linear regression analysis indicated that Zn content of grain and Zn grain uptake accounted for 89.64 and 89.01% variation in yield of rice (Fig. 2). The results are in agreement with Nawaz *et al*. (2004), Hussain and Yasin (2004), Nathan *et al*. (2005) and Charati and Malakouti (2006).

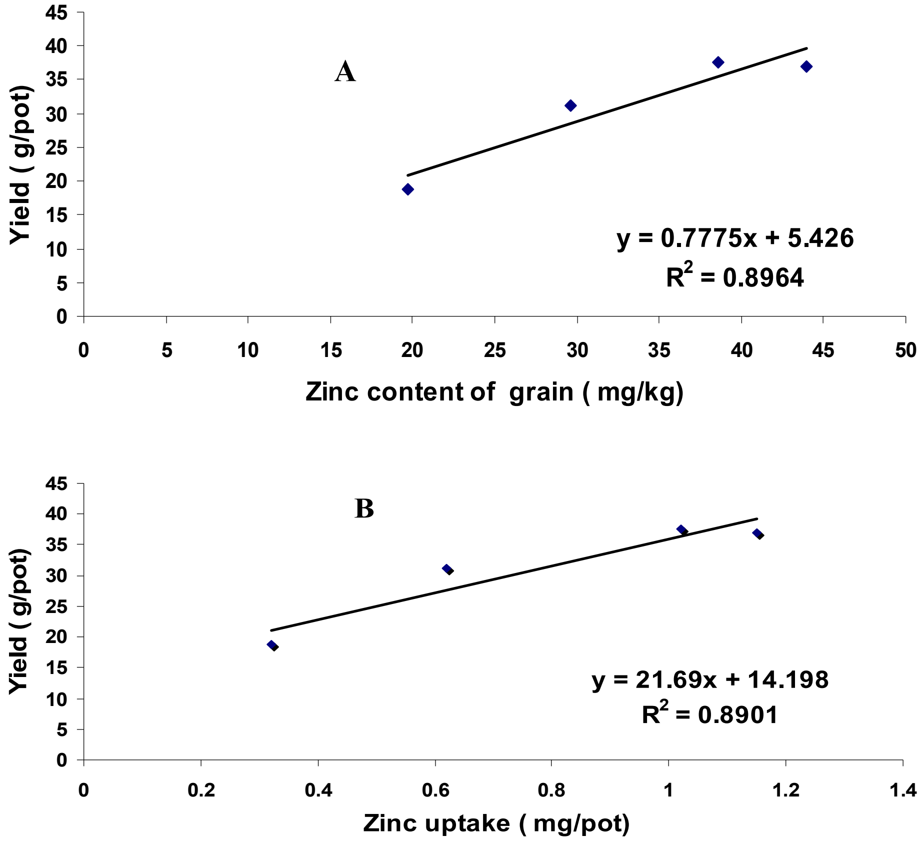


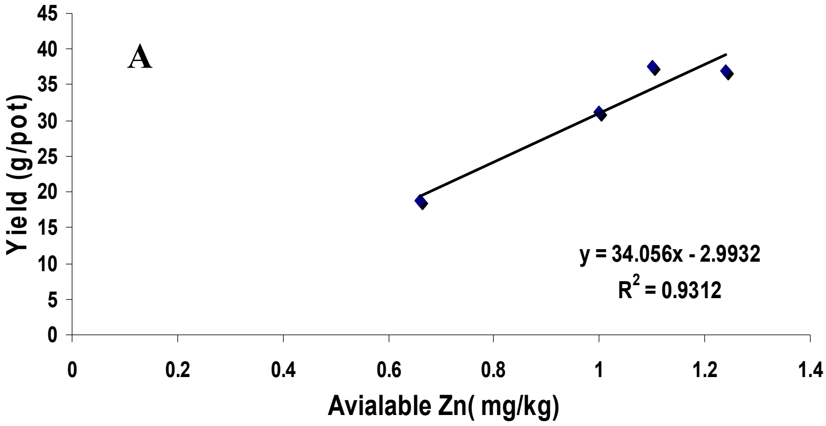
Fig. 2. Interrelationship between grain yields with A) zinc content in grain B) zinc uptake

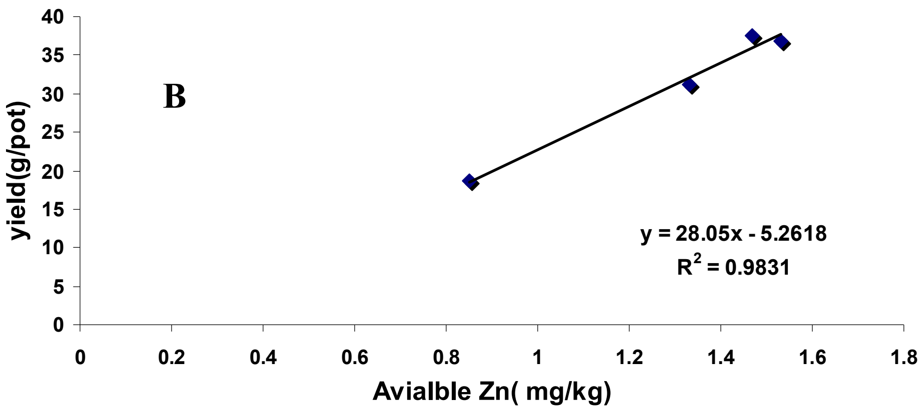
Zinc concentration in soil

The application of zinc in rice significantly affected the concentration of zinc in soil over check (Table 2) that ranged from 0.89 to 1.53 mg kg^{-1} at tillering stage, 0.69 to 1.45 mg kg^{-1} at panicle initiation and 0.66 to 1.24 mg kg^{-1} at harvest. The highest concentration of DTPA-Zn was observed with 7.5 mg Zn kg^{-1} at all stages of crop growth. And it is due to higher solubility, diffusion and mobility of applied Zn (Chitdeshwari and Krishnasamy, 1997). DTPA- Zn (at harvest) decreased from their initial amount (at tillering) on submergence might be due to formation of insoluble carbonates or sulfides (Hazra and Biswapati Mandal, 1988). Linear regression analysis indicated that DTPA-Zn at tillering, panicle initiation and harvest stages accounted for 98.31, 96.34 and 93.12% variation in yield of rice (Fig. 3). This signifies the importance of sufficient availability of DTPA- Zn at early stages of rice growth and any zinc deficiency at this stage would repair grain production. Increase in zinc content in soil due to zinc application was reported by earlier workers (Rahamatullah Khan *et al*., 2007; Naik and Das, 2007; Chaudhary *et al*., 2007).

Table 2. Effect of zinc application on DTPA-Zn (mg/kg) by rice crop at various Stages of crop growth

Zn-Levels	**Tillering stage**			**Panicle initiation**			**Harvest stage**		
(mg/kg)	**S_1**	**S_2**	**Mean**	**S_1**	**S_2**	**Mean**	**S_1**	**S_2**	**Mean**
0	0.75	0.95	0.85	0.65	0.85	0.69	0.58	0.77	0.66
2.5	1.26	1.40	1.33	1.06	1.27	1.16	0.90	1.10	1.00
5.0	1.34	1.63	1.47	1.16	1.48	1.32	0.98	1.25	1.10
7.5	1.43	1.66	1.53	1.20	1.50	1.45	1.10	1.30	1.24
Mean	1.18	1.41		1.01	1.27		0.89	1.30	
	Zn	S	Zn ×S	Zn	S	Zn ×S	Zn	S	Zn× S
SE_D	0.008	0.006	0.012	0.008	0.005	0.011	0.008	0.005	0.011
CD(p=0.05)	0.018.	0.013	0.025	0.016	0.011	0.023	0.017	0.012	0.024





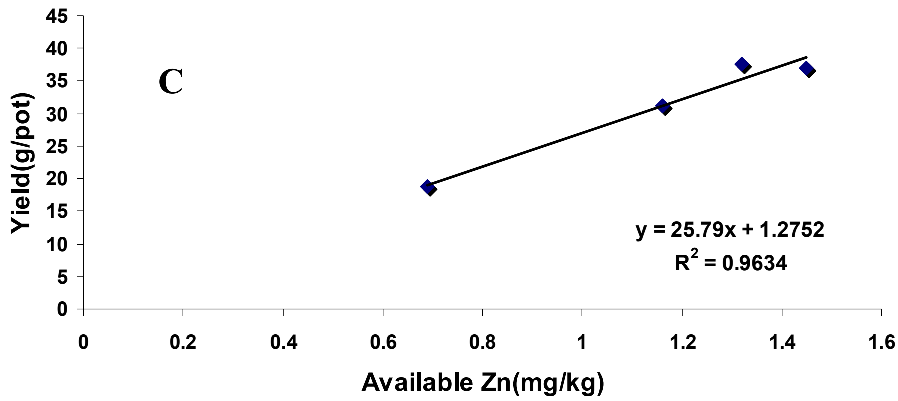


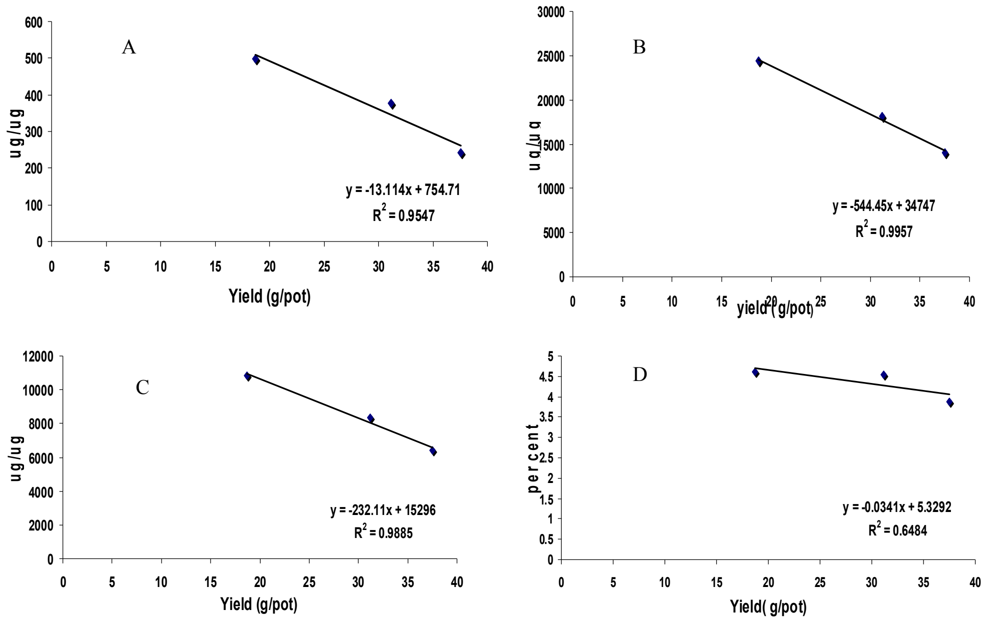
Fig 3. Interrelationship between grain yield with available zinc A) Tillering stage B) Panicle Initiation stage C) Harvest stage

Zinc Use efficiency

Zinc use efficiency (ZnUE) has been defined in five ways (Fageria and Baliger, 2001) and on ZnUE is presented in Table 3. Agronomic, physiological and agrophysiological efficiencies apparent Zn recovery and Zn utilization efficiency decreased significantly with Zn levels. This was due to inverse relationship often observed between utilization and rate of application. The decrease in zinc use efficiency with increase in Zn rates was also due to progressive decline ingrain yield or DMP at higher levels of Zn applied. Higher ZnUE at lower Zn level was reported by Genc *et al*. (2002) in barley genotypes and Fageria *et al*. (2011) in rice. Applied Zn recovery was 4.3% across Zn rates. The result is in agreement with Mortvedt (1994) who reported relatively low (5 to 10%) for crop recovery of micronutrients which was due to poor distribution from low rates applied fertilizer reaction with soil to form insoluble products. The linear regression analysis indicated agronomic, physiological and agrophysiological efficiencies. The apparent Zn recovery and Zn utilization efficiency accounted for 95.43, 99.57, 98.89, 64.84 and 97.09% variation in yield of rice (Fig.4). This relationship clearly demonstrated the importance of ZnUE to the rice yield with special emphasis on physiological and agrophysiological efficiency which accounted for the maximum variation.

Table 3. Zinc use efficiency in lowland rice as influenced by Zn application rate

Zn-rate (mg kg^{-1})	Agronomic efficiency ($\mu g \mu g^{-1}$)			Physiological efficiency ($\mu g \mu g^{-1}$)			Agro Physiological efficiency ($\mu g \mu g^{-1}$)			Apparent recovery efficiency (%)			Utilization efficiency ($\mu g \mu g^{-1}$)		
	S_1	S_2	Mean	S_1	S_2	Mean	S_1	S_2	Mean	S_1	S_2	Mean	S_1	S_2	Mean
2.5	480	517	499	23047	25821	24434	11215	10512	10864	4.28	4.92	4.60	987	1270	1128
5.0	367	386	377	18125	18211	18168	8827	7841	8334	4.16	4.92	4.54	754	896	825
7.5	236	248	242	15228	12882	14055	7336	5474	6405	3.21	4.53	3.87	489	584	536
Mean	361	384	-	18799	18972	-	9126	7942	-	3.88	4.79	-	743	917	-
	Zn	S	Zn xS	Zn	S	Zn x S	Zn	S	Zn x S	Zn	S	Zn xS	Zn	S	Zn xS
SE_d	0.80	0.65	1.13	2.74	2.24	3.88	0.64	0.53	0.91	0.05	0.04	0.07	0.64	0.53	0.91
CD (p=0.05)	1.70	1.39	2.41	5.85	4.78	5.28	1.38	1.13	1.95	0.11	0.09	0.16	1.38	1.13	1.95



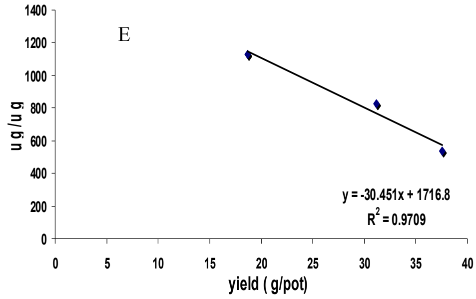


Fig.4. Interrelationship between grain yield with A) Agronomic efficiency B) Physiological efficiency C) Agrophysiological efficiency D) Apparent Zn recovery E) Zn utilization efficiency

Conclusion

It was observed that rice yield significantly improved with zinc fertilization in Zn deficient soil. The highest DMP and yield was noticed with 5 mg Zn kg^{-1} while zinc content, uptake and DTPA-Zn were highest with 7.5 mg Zn kg^{-1}. Zinc content, uptake, DTPA-Zn and ZnUE had significant positive linear relationship with grain yield of rice

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