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Research Paper

Effect of levels and sources of zinc on growth, yield and economics of rice (*Oryza sativa*) under temperate conditions

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ABSTRACT

A field experiment was conducted during the rainy (*kharif*) seasons of 2011 and 2012 on silty clay loam soil of Khudwani, Anantnag, Jammu and Kashmir medium in Zn with neutral *p*H, to assess the response of rice (*Oryza sativa* L.) to levels and sources of Zn. Factorial combinations of 3 levels of Zn (3, 6 and 9 kg/ha), supplied through 5 sources ($ZnSO_4$, ZnO, zinc-enriched urea, Zn-FYM incubated and Zn-EDTA) and 1 absolute control was laid out in randomized complete block design with 3 replications. A significant response was observed to Zn application up to 6 kg/ha in respect of growth parameters like plant height, leaf-area index (LAI), dry-matter accumulation, and number of tillers/hill. The Zn sources had a significant effect on LAI and number of tillers only. Yield attributes, namely panicles/m^2, panicle length, and grains/panicle, also got significantly increased up to 6 kg Zn/ha and the same were at par with 9 kg Zn/ha. Application of 3 and 6 kg Zn/ha increased the grain yield by 5.7% and 10.9% over the control, respectively, during 2011. The corresponding figures for the year 2012 were 7.1% and 14.3%. The data averaged over 2 years showed that Zn-EDTA though at par with Zn-enriched urea and Zn-FYM incubated, realized 6.4% and 7.6% higher grain yield compared to ZnO and $ZnSO_4$ respectively. Zinc concentration in brown rice averaged over 2 years increased from 38 to 49 mg/kg with the increase in Zn application rates from 3 to 9 kg/ha respectively. The Zn-EDTA resulted higher Zn concentration of 46.4 mg/kg respectively in brown rice, but was statistically at par with zinc-enriched urea and Zn-FYM incubated. Although the highest mean benefit: cost ratio of 1.78 was realized at 3 kg Zn/ha, the highest mean net returns of ₹82.85 × 10^3 were realized at 6 kg Zn/ha. Among the sources, the highest and comparable net returns and benefit: cost ratio were realized for Zn-FYM incubated and Zn enriched urea.

Key words : Grain yield, Rice, Zinc enriched urea, Zinc sulphate, Zinc oxide, Zinc concentration

Rice is the premier food crop of India and therefore, national food security system largely depends on the rice productivity. Among the rice-growing countries India ranks first in area (43.8 m ha) and second in production (105.0 mt), next only to China. However, the average productivity of rice in India is only 3.44 t/ha against the global average of 4.0 t/ha (FAO, 2014). Increasing productivity and production are essential to meet the food requirement of the burgeoning population. In Jammu and Kashmir, the rice crop is cultivated over an area of 259.0 thousand hectares with a production of around 576 thousand tonnes. (DES, 2013–14). The Kashmir valley with temperate climate has a unique set of varieties suited to its agro-climatic situation. The abundant sunshine with nearly pest-free environment makes this region suitable for good rice yields. In spite of this fact, the average yields (3.24 t/ha) are far below the potential yields (7 t/ha) due to several constraints, the main among them being poor soil fertility, weed infestation and poor adoption of recommended package of practices etc. The use of only major nutrients has resulted in mining of secondary and micronutrients. Further, it is anticipated that further increase in incidences with the advent of rice with Zn dense grains for human nutrition will increase the demand for Zn.

The widespread of zinc deficiency and its role in rice crop productivity, animal and human nutrition deserves special attention. Numerous studies have indicated that zinc deficiency is a serious nutritional problem for crops.

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An analysis of 233,003 soil samples taken from different states showed that 47% of Indian soils are deficient in Zn (Takkar, 1996). The average micronutrient status of rice soils of Kashmir in general is adequate except zinc, which is marginally low (Wani *et al*., 2013). Application of Zn fertilizers or Zn-enriched NPK fertilizers (agronomic biofortification) offers a rapid solution to the problem. In India, zinc deficiency is more widespread in the rice–wheat cropping system belt of north-western India, which has high *p*H calcareous soils (Prasad, 2006).

Zinc deficiency in cereal plants is a well-known problem that causes reduced agricultural productivity all over the world. Response of rice to zinc has been reported by several workers in India (Shivay *et al.,* 2008). The general recommendation for rice–wheat system in India is soil application of 10 to 25 kg/ha zinc sulphate (Takkar, 1996). The Zn recommendation for rice for the site is 15 kg zinc sulphate/ha. Zinc sulphate ($ZnSO_4$) is the most widely applied inorganic source of Zn due to its high solubility and low cost. Zinc can also be applied to soils in the form of ZnO, Zn-EDTA and Zn-FYM incubated FYM. These sources have been reported to vary in their efficacy. Keeping in view the importance of zinc fertilization, a field experiment was conducted to study the effect of zinc fertilization on growth, yield and economics of rice under Kashmir valley conditions.

MATERIALS AND METHODS

A field experiment was conducted at Mountain Research Centre for Field Crops, Khudwani of Sher-e-Kashmir University of Agricultural Sciences and Technology of Kashmir. The experimental site is situated in temperate zone of Jammu and Kashmir State between (34^o N' and 74^o E' and at an altitude of 1,560 m above mean sea-level). The experiment was conducted during the rainy (*kharif*) seasons of 2011 and 2012 on slity clay-loam soil, neutral in *p*H (6.78), low in nitrogen (215 kg/ha), medium in available phosphorus (14.2 kg/ha), and potassium (205 kg/ha), and medium in zinc (0.62 mg/kg). The rainfall received during crop-growing season, extending from May to October for 2011 and 2012 was 32 mm and 60 mm respectively.

The experiment comprised 2 factors, viz. 3 levels (3, 6 and 9 kg Zn/ha) and 5 sources of zinc (zinc sulphate heptahydrate, zinc oxide, zinc-enriched urea, zinc-FYM incubated and Zn-EDTA), and an absolute control, i.e. no zinc, was laid out in a randomized complete-block design with 3 replications. Sowing was done in the first week of May and transplanting was carried out during the first week of June; with 30 days old seedlings, transplanted at a spacing of 15 cm × 15 cm. Well-decomposed farmyard manure (FYM) @ 10 t/ha was applied to experimental sites at the time of lay out of the field. Recommended dose of phosphorus (60 kg P_2O_5/ha) and potassium (30 kg K_2O/ha) through diammonium phosphate and muriate of potash, respectively, was uniformly applied to each plot as basal dose before transplanting the seedlings. Nitrogen @ 120 kg/ha was applied through urea with half as basal and remaining half in 2 equal splits at tillering and panicle initiation stages. As per the treatments, wherever zinc was to supplied through Zn-enriched urea, the entire dose of Zn was supplied through the Zn-enriched urea as basal dose. In the plots where the Zn was supplied through Zn-FYM incubated, the recommended dose of FYM and Zn as per the treatments was applied through Zn-FYM incubated. The crop was irrigated by maintaining a water level of 3–5 cm up to flowering stage but drained at 20 and 50 DAT. During the grain filling, the crop was irrigated intermittently.

Leaf-area index (LAI) was measured with canopy analyser Accupar LP-80. Plant height and number of tillers/hill were recorded from 10 randomly tagged hills from each plot. Panicles/m^2 were calculated from data collected from number of tillers/m row length at maturity. The biological yield was taken from net plots. The straw yield was computed by deducting the grain yield from the total biological yield and the grain yield data were adjusted at 14% moisture content. The statistical analysis of the data was performed using Microsoft Excel and MSTAT-C softwares. Statistical significance between mean differences among treatments for various parameters was analyzed using critical differences (CD) at 0.05 probability level.

RESULTS AND DISCUSSION

Growth attributes

Significantly taller plants, higher number of tillers/hill, leaf-area index and dry-matter accumulation were recorded at 6 kg Zn/ha than 3 kg Zn/ha and the control (Table 1). As a result of high photosynthetic and hormonal activity, the meristematic growth in the apical region resulted in the sufficient elongation of the plants owing to Zn application. Shivay *et al.* (2010) reported a positive response of plant height in rice to Zn application. The application of Zn corrected the deficiency of the soil and resulted in improved enzymatic activity and auxin metabolism in rice plants. Among the different zinc sources, significantly higher plant height, increased in number of tillers/hill, LAI and dry-matter accumulation were recorded with Zn-EDTA, than ZnO and $ZnSO_4$, but were at par with that obtained with zinc enriched urea and Zn-FYM incubated. Since the sources differ in their chemistry and solubility, Zn-EDTA maintains the availability of Zn over prolonged time. This might have been the reason for its superiority to $ZnSO_4$ and ZnO. Zinc-enriched urea and Zn-FYM incubated might also have favourably altered the Zn dynamics in soil to prolong its availability for better rice growth and tillering. Superiority of Zn-EDTA (Gangloff *et al.*, 2002) and Zn-enriched urea (Shivay *et al*., 2008) has been reported in large number of agro-ecologies. Application of Zn to soil might have enhanced the hormonal and enzymatic activity for faster leaf expansion resulting in higher leaf-area index. In lowland rice-producing areas, zinc deficiency is associated with calcareous soils and is accentuated by prolonged flooding. Slaton *et al.* (2005) reported positive dry-matter production response to Zn application.

The superiority of Zn-EDTA to the other Zn sources has been widely reported and attributed to its higher and prolonged availability. The Zn-enriched urea has also been reported to be superior Zn source. Incubation of Zn with FYM might have resulted in the chelation of Zn with the organic ligands during the decomposition process. These findings confirm the results of Mehdi *et al.* (1990).

The Zn-EDTA registered a numerical superiority in respect of dry-matter accumulation but was at par with Zn-enriched urea and Zn-FYM incubated but significantly superior to $ZnSO_4$ and ZnO. Synthetic chelates, compounds formed through coordination linkage of chelating agents like EDTA with metal ions, have typically 2 to 5 times more agronomic effectiveness than their respective sulphate salts. Zinc-enriched urea and Zn-FYM incubated also might have altered the solubility and availability of Zn over prolonged period of time. These are expected to provide Zn to the plants over an extended period of time. It is in line with the findings of Karak *et al.* (2005).

Yield attributes

The data (Table 1) indicate that among different zinc levels application of 6 kg Zn/ha significantly increased panicles/m^2, panicle weight, panicle length, grains/panicle and 1,000-grain weight over 3 kg Zn/ha and the control, but the same were at par with 9 kg Zn/ha. It is evident that application of Zn stimulated rice growth, enhanced the tiller production which was finally manifested in superior yield attributes. The increase in the number of panicles/m might be attributed to adequate Zn supply which may have increased the supply of other nutrients and stimulated the overall plant growth. Veeranagappa *et al*., (2010) also reported increase in number of panicles/m^2. Zn-EDTA, Zn-enriched urea and Zn-FYM incubated were superior in producing panicles/m^2. It is in line with the findings of Karak *et al.* (2005) and Mehdi *et al.* (1990). The increase in the number of grains/panicle might have been owing to its enhancing effect on the physiological activities, photosynthesis and translocation and assimilation of photosynthates and formation of higher number of spikelets during the spikelet initiation process which ultimately resulted in higher number of grains/panicle. These findings are in line with those of Muhammad *et al.* (2002). Increase in the

Table 1. Growth and yield attributes of rice as affected by levels and sources of zinc (mean data of 2 years)

Treatment	Plant height (cm)	Tillers/ hill	Dry-matter accumulation (t/ha)	LAI	Panicles/m^2	Panicle weight (g)	Grains/ panicle	1,000-grain weight (g)
Zinc levels (kg/ha)								
3	121.1	11.4	16.6	4.65	410	2.08	88.1	23.6
6	130.2	12.4	17.3	5.03	429	2.23	95.2	24.9
9	133.0	12.7	17.5	5.05	431	2.29	97.1	25.0
SEm±	2.33	0.47	3.94	0.09	7.57	0.07	2.22	0.49
CD (P=0.05)	4.76	0.96	8.05	0.19	15.47	0.15	4.5	0.99
Zinc sources								
Zinc sulphate	128.4	11.3	16.5	4.75	414	2.17	90.0	24.3
Zinc oxide	126.2	11.0	16.4	4.72	406	2.14	89.4	24.2
Zinc-enriched urea	128.9	12.8	17.6	5.02	430	2.21	95.3	24.7
Zinc-FYM incubated	129.6	12.4	17.6	5.01	429	2.21	95.1	24.4
Zn-EDTA	128.5	13.0	17.7	5.07	436	2.26	96.7	24.9
SEm±	3.01	0.61	10.15	0.12	9.78	0.09	2.86	0.62
CD (P=0.05)	NS	1.25	5.09	0.25	18.97	NS	NS	NS
CD (Zn × sources)	NS	NS	NS	NS	NS	NS	NS	NS
Control	112.0	9.97	14.85	4.28	384	1.9	82.6	22.5
SEm±	4.26	10.82	6.83	0.16	11.12	0.12	3.84	0.84
CD (P=0.05)	8.26	1.68	13.95	0.34	26.8	0.25	7.85	1.74
CD (Control vs Zn)								

Table 2. Effect of levels and sources of zinc on grain yield, straw yield and harvest index of rice

Treatment	Grain yield (t/ha)		Straw yield (t/ha)		Zn concentration in brown rice (mg/kg)	Cost of cultivation ($\times 10^3$ ₹/ha)	Net returns ($\times 10^3$ ₹/ha)	Benefit: cost ratio
	2011	2012	2011	2012				
Zinc levels (kg/ha)								
3	7.03	7.22	8.20	8.68	38.2	45.74	81.41	1.78
6	7.38	7.71	8.94	9.27	45.2	50.63	82.85	1.63
9	7.41	7.73	8.99	9.29	49.2	55.51	77.99	1.40
SEm±	0.13	0.17	0.19	0.26	1.05	-	-	-
CD (P=0.05)	0.26	0.34	0.39	0.52	2.14	-	-	-
Zinc sources								
Zinc sulphate	7.11	7.30	8.43	8.75	42.1	41.73	85.30	2.04
Zinc oxide	7.03	7.21	8.37	8.64	41.8	41.65	86.83	2.08
Zinc-enriched urea	7.45	7.84	8.90	9.31	45.4	41.92	92.95	2.22
Zinc-FYM incubated	7.39	7.60	8.88	9.27	45.3	42.09	93.13	2.21
Zn-EDTA	7.47	7.86	8.96	9.38	46.4	85.75	45.53	0.53
SEm±	0.16	0.22	0.24	0.33	1.35			
CD (P=0.05)	0.33	0.44	0.50	0.67	2.76	-	-	-
CD (Zn × sources)	NS	NS	NS	NS	NS	-	-	-
Control	6.65	6.74	7.64	8.16	30.4	40.75	75.25	1.46
SEm±	0.22	0.23	0.33	0.44	1.82	-	-	
CD (P=0.05)	0.45	0.46	0.57	0.60	3.71	-	-	-
CD (Control vs Zn)								

panicle length, number of grains/panicle was reflected in increased panicle weight. However, the response was significant only up to 6 kg Zn/ha. Different Zn sources failed to produce any significant difference in 1,000-grain weight.

Grain and straw yields

Application of 3 and 6 kg Zn/ha increased the grain yield by 5.7% and 10.9% over control during 2011 respectively. The corresponding figures for the year 2012 were 7.1% and 14.3% respectively. The data averaged of 2 years showed that Zn-EDTA though at par with Zn enriched urea and Zn-FYM incubated, realised 6.4% and 7.6% higher grain yield compared to ZnO and $ZnSO_4$ respectively. Among the different zinc sources used, Zn-EDTA had a significant advantage over ZnO and $ZnSO_4$ during both the years. These findings are in line with those of Muhammad *et al.* (2002).

Although the highest straw was recorded with the application of 9 kg of Zn/ha but the same was at par with 6 kg Zn/ha. On an average, application of 3 and 6 kg Zn/ha increased the straw yield by 5.81% and 11.99% over the control. Slaton *et al.* (2005) reported positive straw yield response to Zn application. Among different zinc sources used, application of Zn-EDTA though at par with zinc-enriched urea and Zn-FYM incubated, significantly increased straw yield over $ZnSO_4$ and ZnO. The percentage increase in straw yield due to Zn-EDTA application over $ZnSO_4$ and ZnO was 6.2 and 7.0 for the year 2011 respectively. The corresponding figures during 2012 were 7.0 and 8.5 respectively.

Zinc concentration in grain

Zinc concentration in brown rice averaged over 2 years increased from 38 to 49 mg/kg with increase in Zn application rates from 3 to 9 kg/ha respectively. The increase in Zn concentration was significant up to 9 kg Zn/ha. The increased Zn concentration in the brown rice was outcome of increased availability, absorption and translocation and deposition of Zn in brown rice. Cakmak (2004) reported similar results. Different Zn sources also significantly affected the Zn concentration in brown rice. The Zn-EDTA recorded higher Zn concentration of 46.4 mg/kg respectively in brown rice, but was statistically at par with zinc enriched urea and Zn-FYM incubated. The Zn-EDTA resulted in a higher Zn content in brown rice to the tune of 8.4, 8.8 and 10.8% over $ZnSO_4$, ZnO and Zn-FYM incubated during 2011. The corresponding figures for the year 2012 were 7.4%, 6.5% and 9.6% respectively.

Economics

Zinc applied @ 6 kg/ha realized the highest net returns of 82.85 $\times 10^3$ ₹/ha but the highest benefit: cost ratio of 1.78 was recorded at 3 kg Zn/ha. Among the Zn sources, the highest net profit was realized for Zn-FYM incubated, which was closely followed by Zn-enriched urea. These 2

Zn sources also registered the highest and almost similar benefit: cost ratio.

From the experiment it was concluded that a significant yield response was obtained only upto 6 kg Zn/ha however, Zn concentration in brown rice increased upto 9 kg Zn/ha. Among the sources, Zn enriched urea and Zn-FYM incubated proved more economical sources of Zn and were equally effective in enhancing the Zn concentration in brown rice when compared with Zn-EDTA.

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