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Research Communication

Effect of zinc fertilization on growth, yield and nutrient uptake of rice (*Oryza sativa*) in Eastern Himalayas

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ABSTRACT

An experiment was conducted during the rainy (*kharif*) season of 2015 at Umiam, Meghalaya, to study the effect of zinc fertilizer on growth, yield and nitrogen uptake in rice (*Oryza sativa* L.). Soil and foliar application of different Zn sources in various concentrations were compared with prilled urea and no-urea application (control). The experiment was laid out in a completely randomized block design with 10 treatments a 3 replications. Application of Zn in different forms produced significantly higher dry matter and root dry weight of rice at different growth stages over the control. Yield attributes and yield of rice crop were higher with the application of 3% Zn-coated urea (ZnCU), followed by soil application of 5.0 kg Zn/ha over the control. The rice crop removed higher amount of N, P, K and Zn from soil with the soil application of 3% ZnCU, but the removal of S was higher with soil application of 5.0 kg Zn/ha than the other treatments. Significant effect on available N and S in soil after rice harvesting was observed owing to application of Zn treatments over no-urea. Soil application of 2% or 3% ZnCU or soil application of 5.0 kg Zn/ha resulted in significantly higher available Zn content in soil over prilled urea and no urea. Application of 3% ZnCU (5.46 t/ha) or soil application of 5.0 kg Zn/ha (5.36 t/ha) showed a trend to increase the grain yield over prilled urea (4.37 t/ha). Application of Zn had positive effect on soil-dehydrogenase enzyme activity but did not influence the soil microbial biomass carbon content. Hence ZnCU is a recommendable option for rice cultivation in North-Eastern Hills region for achieving sustainable production and improving soil health.

***Key words*:** Growth, North-Eastern hills (NEH) region of India, Rice, Uptake, Yield, Zinc, Zn-coated urea

Rice (*Oryza sativa* L) is the second largest consumed cereal after wheat and contributes about 80% of the food calorie requirements in the world. India stands first in terms of area (43.8 million ha) with 116.4 million tonnes and 2.66 t/ha production and productivity respectively, in 2018–19. In North-Eastern Region (NER) of India, rice is the principal foodgrain crop, and nutritional security of household predominantly depends on it. Comparing to other parts of the country, NER of India has great potential to produce rice due to its favourable climatic conditions. However, the average productivity of the rice in the region (2.0 t/ha) is much below the national average (*Das et al.*, 2020). The reason behind this low productivity may be due to diverse biotic or abiotic stresses like poor nutrition, drought, pests, and low-yielding varieties among others.

Rice is highly sensitive crop to Zn deficiency. Forty-four per cent of Indian soils are reported Zn-deficient (*Shukla et al.*, 2012). Zinc is one of the most important micronutrients essential for plant growth especially for rice grown under lowland condition. Rice plants deficient in Zn show poor root respiration especially under flooded conditions (*Slaton et al.*, 2001). Zinc deficiency in lowland rice fields occurs due to its chemical precipitation with sesquioxides and rendering it unavailable to plants (*Mandal et al.*, 2000). Zn is essential for several biochemical activities such as metabolism of auxin, activation of enzyme, production of chlorophyll, required as a cofactor for over 300 enzymes which plays a central role in detoxification of reactive oxygen

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species in plant cells (*Broadley et al.,* 2007).

Application of Zn has been reported to improve the chlorophyll content, number of tillers per plant, total biomass and yield of rice, as well as the Zn concentration in the grain and the straw (*Ghasal et al.*, 2018). Among the methods of Zn application, soil application is reported to give better response in terms of higher yield and biomass production than other methods. Although, foliar application of Zn is a promising method to increase Zn concentration in seed. However, there is very little information on the effectiveness of foliar Zn applications on Zn concentrations of rice grain. The role of timing of foliar Zn spray in increasing grain Zn concentration is also limited in NER of India. In view of these facts, a field experiment was conducted to study the effects of Zn fertilization on growth, yield, nutrient uptake and soil fertility under rice in Eastern Himalayas, India.

The field experiment was carried out at research farm of the ICAR Research Complex for North-Eastern Hill (NEH) Region, Umiam (25°41'N, 91°54' E, 980 m above the mean sea-level) in Ri-Bhoi district of Meghalaya during the *kharif* season of 2015. The experimental site recorded a total rainfall of 1,954.1 mm during the crop season. The average maximum and minimum temperature during the cropping season was 29.0°C and 9.7°C, respectively, and the mean relative humidity in the morning and evening was 85.9% and 74.7% respectively.The soil type of the experimental site was clayey loam with moderately acidic *p*H (4.51), high in soil organic carbon (2.8%), low in available N (278.8 kg/ha) and P (18.87 kg/ha), medium in available K (125.36 kg/ha), low in available S (12.39 kg/ha) and adequate in available Zn (2.06 mg/kg).

The field experiment consisted of 10 treatments, viz. 1% Zn-coated urea (ZnCU), 2% ZnCU, 3% ZnCU, soil application of 2.5 kg Zn/ha, soil application of 5.0 kg Zn/ha, 0.1% Zn foliar spray at panicle-initiation (PI) stage, 0.1% Zn foliar spray at PI and flowering stages, 0.1% Zn foliar spray at PI, flowering and grain-filling stages, and compared with prilled urea and no-urea (control). The experiment was laid out in a completely randomized block design with 3 replications. Dry nursery was prepared for raising rice seedlings of variety 'Shahsarang 1'. Rice seeds were soaked in water overnight before the day of sowing and were sown by broadcasting uniformly on the nursery seedbed. Seedlings were raised carefully until they were ready for transplanting in the main field. Two to three healthy seedlings at 4–5-leaf stage were transplanted in a square geometry with plant-to-plant and row-to-row distance of 20 cm × 20 cm. Urea, single superphosphate and muriate of potash were used as source of nutrients to supply the recommended dose of N, P and K, i.e. 80 : 26.2 : 33.3 respectively. Half of the recommended dose of N along with full recommended doses of P and K was incorporated to the soil as basal application at the time of field preparation for transplanting to fulfil the initial requirements of the crop and the remaining amount of N was top-dressed in two split doses at 30 and 60 days after transplanting (DAT). In no-urea treatment, recommended dose of P and K was applied basal.

Soil and foliar applications of Zn were done through $ZnSO_4.7H_2O$ at the required stages as per the treatment. $ZnSO_4.7H_2O$ was mixed with urea and applied through broadcasting to the crop. Half dose of ZnCU was applied basal to the soil and the remaining half in equal split doses at 30 and 60 days after transplanting by broadcasting. The ZnCU has replaced regular urea in the treatment which is easy to apply to crop like urea and do not need any special knowledge for soil application. When applied at the field, 1%, 2% and 3% ZnCU supplied 2.6 kg Zn/ha, 5.2 kg Zn/ha and 7.8 kg Zn/ha respectively, while foliar application at 0.1% zinc supplied 1 kg Zn/ha every time. $ZnSO_4.7H_2O$ 100 g plus 50 g unslaked lime dissolved in 20 litres water to make 0.1 % zinc solution. Application of 1,000 litres/ha of water was used for each foliar spray.

Plant and soil samples (0–15 cm depth) from each treatment of the experiment were drawn and analysed for different nutrient content as per the procedures described by *Prasad et al.* (2006). Uptake of N, P, K, S (kg/ha) and Zn (g/ha) in grain and straw of rice was calculated by using the formula given below. Total nutrient uptake (kg/ha) by rice was obtained by adding the nutrient uptake of grain and straw.

Nutrient uptake by grain (kg/ha) = % nutrient concentration × grain yield (t/ha) × 10

Nutrient uptake by straw (kg/ha) = % nutrient concentration × stover yield (t/ha) × 10

Data were statistically analysed in completely randomized block design using the technique of Analysis of Variance (ANOVA). Significance of differences between the treatment means was tested with critical difference (CD) value at 5% level of probability.

Dry-matter accumulation improved significantly with Zn application along with NPK fertilization over no-urea at harvesting (Table 1). Application of 3% ZnCU to the soil significantly increased dry-matter production at harvesting being at par with soil application of Zn 5.0 kg/ha over prilled urea and 1% ZnCU. Among the treatments, minimum dry-matter was obtained under prilled urea, followed by 1% ZnCU and soil application of Zn 2.5 kg/ha. *Fageria et al*. (2011) reported significant increase in shoot dry weight of rice due to application of Zn to the soil over the control. *Singh et al*. (2012) also reported higher dry matter of rice at maturity and tillering stage with soil application of 6 kg Zn/ha than no-Zn application.

Root dry weight was affected significantly with application of different treatments at harvesting over no-urea, prilled urea and 0.1% foliar Zn spray at panicle initiation (PI). At harvesting, highest root dry weight was recorded in 3% ZnCU (14.35 g/hill) followed by soil application of 5.0 kg Zn/ha and found superior to no-urea and prilled urea. Wang *et al*. (2014) reported that, root dry weight was significantly improved owing application of Zn along with N fertilization.

Yield attributes responded significantly to Zn fertilization. Application of 3% ZnCU resulted in significantly greater number of panicles/hill than prilled urea and no-urea, whereas the soil application of $ZnSO_4$ or foliar spray of Zn did not differ significantly over prilled urea and remained at par with each other (Table 1). Application of 3% ZnCU urea or soil application of 5.0 kgZn/ha recorded relatively higher panicle weight and number of grains/panicle over prilled urea and no-urea. The Zn fertilization along with N proved to exhibit a marked change in grain weight/panicle over no-urea application. Application of 3% ZnCU resulted in the maximum grain weight/panicle, followed by soil application of 5.0 kg Zn/ha and 0.1% foliar Zn spray at PI, flowering and grain filling and remained superior to prilled urea and no-urea. Zn fertilization has been previously reported to improve yield attributing parameters of rice like spikelet/panicle and grain-filling percentage (*Wang et al.*, 2014). No significant differences were found pertaining to 1,000-seed weight of rice due to Zn fertilization.

Most of the Zn is mobilized to seed only at the time of fertilization (*Singh et al.*, 2012) or may be due to involvement of carbonic anhydrase activity and more carbohydrate accumulation in seeds (*Saha et al.*, 2013). On account of this, all the yield-attributing traits were recorded higher in the Zn treatments over no-urea and prilled urea. Among the treatments, an application of 3% ZnCU resulted in the maximum improvement in yield attributes of rice over prilled urea. This might be because of adequate supply of Zn to the crop which thereby had enhanced various metabolic and physiological functions such as photosynthesis, and translocation of photosynthates to the reproductive part of the plant and enhanced uptake of other essential nutrients (*Alloway,* 2008). *Ghasal et al.* (2015) also reported that, application of Zn significantly increased yield attributes of rice.

Application of Zn along with NPK significantly increased the grain and straw yields of rice over no-urea (Fig. 1). The highest grain and straw yields were obtained with the application of 3% ZnCU (5.46 and 7.09 t/ha, respectively) followed by soil application of 5.0 kg Zn/ha (5.36 and 7.05 t/ha respectively), which were at par with each other and resulted in significantly higher grain yield than prilled urea (4.37 and 5.76 t/ha respectively). These treatments also resulted in superior yields over 0.1% foliar application of Zn at PI stage. No significant differences were observed pertaining to harvest index. The maximum rice yields were achieved at the highest enrichment of the prilled urea with Zn. The significant effect on grain yield is associated with the combined improvement of yield attributes like number of panicles, panicle weight, number of grains and grain weight/panicle. The increase in grain and straw yields of rice with Zn fertilization might be because of the fact that Zn plays an important role in biosynthesis of the indole-acetic acid and initiation of primordia for reproductive parts and favourable effected on the metabolic

Table 1. Effect of zinc fertilization on dry-matter accumulation, root dry weight and yield attributes of rice

Treatment	Dry-matter accumulation at harvest (g/hill)	Root dry-weight at harvest (g/hill)	Panicles/ hill	Panicle weight (g)	Grains/ panicle	Grain weight/ panicle (g)	1,000–seed weight (g)
1% Zn-coated urea	79.2	12.07	11.6	4.43	151.5	3.69	25.02
2% Zn-coated urea	83.2	13.07	12.3	4.56	155.2	3.83	25.14
3% Zn-coated urea	96.4	14.35	13.1	4.82	164.1	4.18	25.14
Soil application of 2.5 kg Zn/ha	79.5	12.97	11.5	4.50	151.3	3.81	25.09
Soil application of 5.0 kg Zn/ha	94.2	14.05	12.4	4.72	163.9	4.14	25.11
0.1% foliar Zn spray at panicle initiation (PI)	83.3	11.76	11.9	4.20	151.1	3.67	24.72
0.1% foliar Zn spray at PI and flowering	83.8	12.49	12.1	4.46	154.2	3.94	25.13
0.1% foliar Zn spray at PI, flowering and grain-filling	84	12.59	12.2	4.48	160.3	4.08	25.07
Prilled urea	77.1	11.09	10.9	4.01	141.8	3.40	24.62
No-urea (control)	49.9	7.45	9.1	3.21	104.4	2.84	24.62
SEm±	3.73	0.54	0.6	0.24	6.41	0.15	0.28
CD (P=0.05)	11.07	1.61	1.79	0.71	19.04	0.44	NS

PI, Panicle initiation

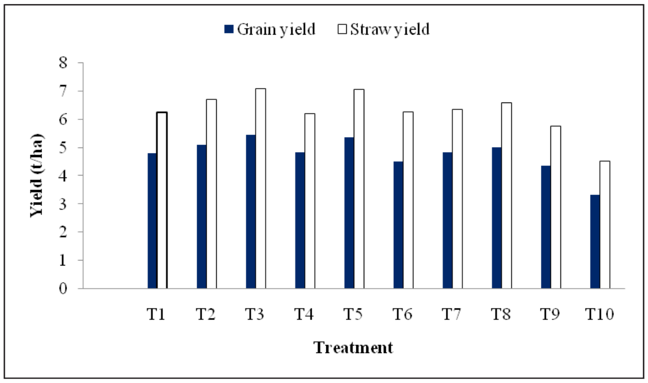

Fig. 1. Effect of zinc fertilization on grain yield and straw yield of rice
T_1, 1% Zn-coated urea (ZnCU); T_2, 2% ZnCU; T_3, 3% ZnCU; T_4, soil application of 2.5 Zn kg/ha; T_5, soil application of 5.0 Zn kg/ha; T_6, 0.1% Zn foliar spray at panicle initiation (PI); T_7, 0.1% Zn foliar spray at PI and flowering stages; T_8, 0.1% Zn foliar spray at PI, flowering and grain filling stages; T_9, prilled urea; T_{10}, no-urea

reactions within the plants (*Keram et al.*, 2012). The superiority of Zn application for grain yield may also be owing to improvement in soil properties and subsequent improvement in root growth and development (*Yadi et al.*, 2012). *Shivay et al.* (2013) and *Wang et al*. (2014) also reported increase in grain and straw yield with Zn fertilization.

Application of 3% ZnCU removed higher amount of N followed by soil application of 5.0 kg Zn/ha than the other treatments (Table 2). Total N, P, and K uptake (grain + straw) of rice varied significantly with application of different Zn treatments. The total uptake of these nutrients was relatively higher with application of 3% ZnCU and soil application of 5.0 kg Zn/ha than 1% ZnCU, 0.1% foliar Zn spray at PI, prilled urea and no-urea. The increase in N availability through synchronized release from ZnCU might be responsible for increased growth of the rice crop (*Jat et al.*, 2011) which consequently improved the N uptake. Nutrient uptake is the resultant of multiplication of nutrient concentration accumulated in the plant tissues with their respective dry-matter yield. Therefore, greater nutrient concentration and significantly higher grain and straw yield of rice due to Zn treatments would be the reason for showing an increasing trend in the total nutrient uptake by the rice crop over no urea and prilled urea.

Soil application of 5.0 kg Zn/ha removed the highest amount of S, followed by 3% ZnCU which were also significantly superior to 1% ZnCU, 0.1% foliar Zn spray at PI, prilled urea and no-urea. The highly water-soluble $ZnSO_4.7H_2O$ made sulphur along with Zn readily available for plant uptake and therefore, resulted in improved S uptake by the rice crop. Improvement in nutrient uptake owing to Zn application was also reported by *Shivay et al.* (2015).

The highest Zn uptake was obtained with soil application of 3% ZnCU, followed by soil application of 5.0 kg Zn/ha and 0.1% foliar Zn spray at PI, flowering and grain-filling which were significantly superior to prilled urea, 1% ZnCU, 0.1% foliar Zn spray at PI. One foliar application of 0.1% Zn at PI stage did not remove Zn from soil as high as with those of 2% or 3% ZnCU and soil application of Zn 5.0 kg/ha. This sharp increase in Zn uptake at a greater Zn level may be related to greater increase in Zn concentration in soil solution. Zinc interacts positively with N which is mainly attributed to the increased availability of Zn in soil owing to acid-forming effect of N (*Prasad,* 2005). Therefore, application of N either through ZnCU or through prilled urea increased the Zn uptake significantly (Jat *et al.*, 2011). *Shivay et al.* (2008) indicated that concomitant application of Zn and urea as ZnCU was more effective than their separate soil application for higher Zn uptake. Application of ZnCU also had the advantage of split application and banding of Zn close to the growing rice plants, which increased its uptake before applied Zn reacted with

Table 2. Effect of zinc fertilization on nutrient uptake by rice

Treatment	N (kg/ha)	P (kg/ha)	K (kg/ha)	S (kg/ha)	Zn (g/ha)
1% Zn-coated urea	97.5	23.5	138.2	9.9	774.4
2% Zn-coated urea	109.2	27.2	155.4	11.1	855.3
3% Zn-coated urea	120.3	30.4	167.5	12.3	935.0
Soil application of 2.5 kg Zn/ha	97.5	24.2	139.2	11.0	761.1
Soil application of 5.0 kg Zn/ha	109.8	29.2	164.4	12.8	926.0
0.1% foliar Zn spray at panicle initiation (PI)	92.6	22.7	140.2	9.5	764.7
0.1% foliar Zn spray at PI and flowering	99.9	23.5	144.8	10.4	833.8
0.1% foliar Zn spray at PI, flowering and grain-filling	104.7	25.7	151.2	11.2	900.6
Prilled urea	87.2	20.4	125.6	8.7	645.5
No-urea (control)	61.6	14.6	92.9	5.9	471.6
SEm±	4.1	1.33	6.89	0.45	38.12
CD (P=0.05)	12.17	3.94	20.46	1.33	113.25

PI, Panicle initiation

water and CO_2 in soil solution and converted it to $ZnCO_3$, rendering it less available to plants (*Yoshida et al.*, 1971).

Results on soil fertility status after crop harvesting as affected by different treatments are presented in Table 3 and Fig. 2. Soil *p*H, soil organic carbon (SOC), available P and K did not vary significantly due to application of different Zn treatments. *Prasad et al.* (2010) reported that, with increasing Zn levels (0, 2.5, 5 and 10 kg Zn/ha), there was no significant change in *p*H. However, available N, S and a Zn in soil significantly increased owing to different Zn treatments over no-urea. The highest available N was recorded in soil under 3% ZnCU, followed by 2% ZnCU. However, different Zn applications along with N fertilization were observed to be at par with each other in respect of soil-available N. The ZnCU is also a type of slow-release nitrogenous fertilizers which enhances the N-use efficiency of the applied fertilizer. Thus, ZnCU decreases N losses via leaching and denitrification and hence, must have considerably improved the available N in soil.

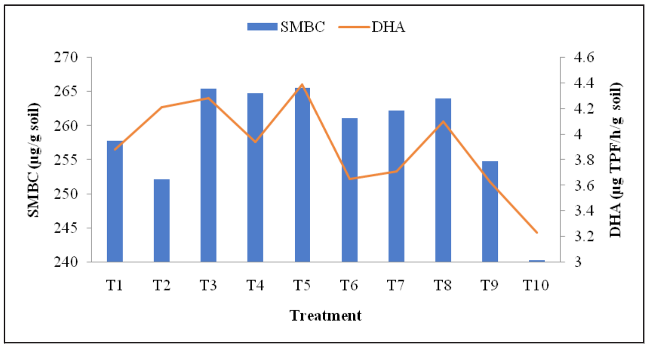

Fig. 2. Effect of zinc fertilization on soil microbial biomass carbon and dehydrogenase contents
T_1, 1% Zn-coated urea (ZnCU); T_2, 2% ZnCU; T_3, 3% ZnCU; T_4, soil application of 2.5 Zn kg/ha; T_5, soil application of 5.0 Zn kg/ha; T_6, 0.1% Zn foliar spray at panicle initiation (PI); T_7, 0.1% Zn foliar spray at PI and flowering stages; T_8, 0.1% Zn foliar spray at PI, flowering and grain filling stages; T_9, prilled urea; T_{10}, no-urea

All ZnCU (1, 2 and 3%) and soil applications of Zn (2.5 kg and 5 kg Zn/ha) improved soil-available S significantly over prilled urea with the highest value in soil under applications of 5 kg Zn/ha (12.44 kg/ha), followed by that under soil applications of 2.5 kg Zn/ha. However, foliar sprays of Zn at different stages did not bring significant changes in available S in soil over prilled urea. The application of Zn in the form of $ZnSO_4.7H_2O$ which contains S might have increased the S content in soil due to addition.

The increasing Zn levels significantly increased the available Zn status in the soil. Application of 3% ZnCU and soil application of 5.0 kg Zn/ha recorded significantly higher Zn content in soil over prilled urea. A decrease in available Zn after rice harvesting in soil from its initial level was observed in all the foliar application of Zn treatments, prilled urea and no-urea. *Singh et al*. (2012) reported significant build-up in case of Zn and S content in the soil with application of S and Zn.

All Zn treatments except 0.1% foliar Zn spray at PI and 0.1% foliar spay at PI and flowering stages had significantly influenced soil dehydrogenase activity (DHA) over no-urea. Higher DHA was recorded under application 5.0 kg Zn/ha to soil, followed by 3% ZnCU and 2% ZnCU than the other treatments. Zinc treatments along with N fertilization brought a significant variation in soil DHA over no-urea. Addition of Zn fertilizers to the soil may have exerted a beneficial effect on enzymatic activity of DHA enzyme and thereby improved its activity in the soil. Application of Zn treatments did not significantly influence soil microbial biomass carbon (SMBC). *Faujdar and Sharma* (2012) also observed no differences in SMBC due to Zn fertilization.

Based on the results, it can be concluded that applica-

Table 3. Effect of zinc fertilization on soil-fertility status after crop harvesting

Treatment	*p*H	Soil organic carbon (%)	Available nutrients				
			N (kg/ha)	P (kg/ha)	K (kg/ha)	S (kg/ha)	Zn (mg/kg)
1% Zn-coated urea	4.58	2.73	280.1	18.1	118.3	11.37	2.04
2% Zn-coated urea	4.59	2.82	283.1	19.0	124.4	11.45	2.24
3% Zn-coated urea	4.58	2.83	287.6	19.1	125.5	11.59	2.36
Soil application of 2.5 kg Zn/ha	4.53	2.80	276.0	19.4	125.7	12.17	2.05
Soil application of 5.0 kg Zn/ha	4.60	2.82	282.8	19.3	126.9	12.44	2.30
0.1% foliar Zn spray at panicle initiation (PI)	4.43	2.82	276.0	17.7	123.1	10.19	1.90
0.1% foliar Zn spray at PI and flowering	4.50	2.79	277.0	16.1	122.0	10.23	1.91
0.1% foliar Zn spray at PI, flowering and grain-filling	4.55	2.82	280.1	18.0	120.6	10.21	1.91
Prilled urea	4.49	2.63	273.4	17.7	120.6	10.06	1.90
No-urea (control)	4.46	2.61	242.7	17.8	127.8	8.22	1.69
SEm±	0.05	0.07	7.3	0.75	3.18	0.34	0.09
CD (P=0.05)	NS	NS	21.7	NS	NS	1.02	0.28

PI, Panicle initiation

tion of Zn fertilizers along with recommended doses of nutrients (NPK) enhanced the growth, yield attributes and yield of the rice crop. Soil application of 3% ZnCU or soil application of 5.0 kg Zn/ha indicated a trend to increase the grain yield. Zinc fertilization with three 0.1% foliar Zn spray at PI, flowering and grain-filling stages increased the Zn uptake in rice. For most of the plant and soil characters studied, ZnCU performed better than soil application of $ZnSO_4$. Therefore, considering ease in application and to supply adequate quantity of Zn to crop, the ZnCU is a promising fertilizer for rice cultivation in NEH region of India.

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