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Effect of foliar zinc nutrition on yield and zinc use efficiency of rice (*Oryza sativa*)

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Abstract
Zinc (Zn) is an essential micronutrient for plants and animals and its deficiency causes large scale yield losses in major crops such as rice. Zn is applied to the plants either through the soil or as foliar spray or both. The present study was carried out to evaluate the effect of foliar application of different concentrations (0, 0.25, 0.5, 0.75 and 1%) of $ZnSO_4.7H_2O$ on biological yield and total zinc uptake of rice cultivar PD-12. Results indicated that foliar application of zinc caused significant changes in most of the parameters under study. With three sprays of 0.25% $ZnSO_4$,a 40.72% increase in economic yield was obtained. Straw yield, biological yield and total zinc uptake was found to be higher when plants were treated with three sprays of 0.5% $ZnSO_4$. Evaluation of agronomical and physiological efficiency revealed that there was decrease in agronomical efficiency with increase in concentration from 0.25% to 0.75% $ZnSO_4$whereas physiological efficiency was found to be increased at 1% $ZnSO_4$.

Keywords: Foliar zinc, biofortification, zinc deficiency

Introduction
Due to the expanding population, there is a global threat to nutritional security, necessitating the implementation of practical and affordable methods in the world food system. Key micronutrient deficiencies like those in Fe and Zn impact more than 2 billion individuals worldwide (Huang *et al*., 2020) [10]. The most typical micronutrient insufficiency is Zn deficiency. Around 50% of agricultural soils worldwide are found to be low in bioavailable Zn (Cakmak, 2011) [6]. Due to the increased pH and calcareous nature of soils, the problem of Zn insufficiency is linked to poor availability and higher Zn adsorption on soil particles (Hussain *et al.*, 2011) [11]. Furthermore, a significant decrease in yield brought on by insufficient soil Zn supply also lowers the Zn content in grains (Alloway, 2009) [1]. The best way to ensure appropriate nutrition is through dietary diversification, yet low-income, impoverished families' diets in developing nations typically consist of staple plant items, and many of these foods, like cereals, are deficient in nutrients (Bouis and Welch, 2010) [3]. Environmental and genetic variables affect rice's grain Zn concentration (Welch and Graham, 2002) [20]. Zn concentrations in grains are typically decreased by factors that diminish soil Zn availability Nakandalage *et al*., 2016 [13]; Cakmak, 2008 [4]; Alloway, 2008 [2]. Therefore, in many circumstances, Zn fertilisation and water management can be useful methods to increase grain Zn Zaman *et al*., 2018 [21]; Tuiwong *et al*., 2021 [18]. Genetic engineering, traditional breeding, and agronomic bio fortification are some of the current methods used to achieve nutritional security. The traditional method involves choosing high-yielding crop varieties already in existence and breeding them with varieties with increased nutrient contents to create staple crops with desired nutrient and agronomic features. Through precise genetic manipulation, it is possible to increase the concentration of micronutrients in edible plant portions. In order to supplement the edible portion of field crops with micronutrients, agronomic bio fortification refers to the use of micronutrient fertilizers through soil application, foliar feeding, or seed treatment (Saeid *et al*., 2019) [14]. The most practical, economical, and practical method for obtaining Zn bio fortification in wheat is regarded to be agronomic bio fortification through Zn fertilisation, particularly by foliar Zn treatment (Cakmak and Kutman. 2018) [7]. Zn is easily transmitted to the growing grain through the phloem after being applied topically to leaves (Curie *et al*., 2009) [8]. In order to increase grain Zn content, foliar Zn application is therefore more effective than soil application Cakmak, 2012 [5]; Saha *et al*., 2017 [15]. Zn must be administered to leaves at modest dosages, often as ZnSO4 at a rate of 1-2 kg ha^{-1} with a solute concentration of 0.3%-0.5%, in order to prevent leaf scorching and environmental concerns.

However, the amount of applied Zn that is absorbed by the plant is quite little (6%), (Wang *et al*., 2015) [19]. Thus, optimizing the efficacy of the foliar-applied Zn and achieving target level of grain Zn while avoiding plant damage and environmental hazards remains a challenge.

Materials and Methods

The present study was carried out at the Norman E. Borlaug Crop Research Center (CRC), G.B. Pant University of Agriculture and Technology, Pantnagar, Uttrakhand, India, during the rainy season, 2021. The experimental site is located in the tarai region at 29º N latitude, 79º 29'E longitude, and at a height of 243.84 meters above sea level. Rice variety Pant Dhan-12 (PD-12) was transplanted in early July and harvested in November.

The experiment was conducted in split plot design with five different levels of Zinc *viz*. 0, 0.25, 0.50, 0.75 and 1.0% applied in the form of $ZnSO_4$. $7H_2O$ as main plot treatments and three different stages of application, S1: One spray at 30 days after transplanting; S2: Two sprays, one each at 30 and 45 days after transplanting; S3: Three sprays, one each at 30, 45 and 60 days after transplanting as subplot treatments. There were four replications for each treatment. Recommended package of practices was followed for growing rice. A handheld sprayer was used for foliar application of zinc sulfate. For estimation of Zn content of flag leaf, sampling was done after completion of three sprays and zinc content of straw and grain was estimated at harvest. Grain yield, biological yield and other yield attributes were recorded at harvest.

Estimation of Zn Use Efficiency

Zn use efficiency was computed by following the formulas suggested by Shivay and Prasad (2012) [17].

Agronomic efficiency = $(GY_{Zn} - GY_C)/ Zn_a$

Physiological efficiency= $(Y_{Zn} - Y_C)/ (U_{Zn} - U_C)$

Where GY_{Zn} is grain yield of Zn-fertilized plots, GY_C is the yield of unfertilized plots, Zn_a is total amount of Zn applied, Y_{Zn} is the grain and straw yield of Zn-treated plots, Y_C is the grain and straw yield of unfertilized plots, U_{Zn} is the Zn uptake in grain and straw of Zn-fertilized plots, and U_C is the uptake of Zn in grain and straw of untreated plots.

Statistical Analysis

The collected data was subjected to statistical analysis by IBM SPSS statistical package (Version 25) and means were separated using Duncan test at 5% level of significance ($p \leq 0.05$).

Results

Yield attributes

Foliar spray of zinc sulfate significantly increased the grain yield, straw yield and biological yield. Among the zinc treated plants maximum grain yield (5.46 t/ha), amounting to an increase of 40.72% over the control plants was observed with three sprays of 0.25% ZnSO4 and minimum (4.67 t/ha) with three sprays of 1% ZnSO4.When ZnSO4 was applied thrice (S3) a significant increase in grain yield was observed for all concentration ranging from 0.24% to 5.6% as compared to S1 (Table 1).

Biological, straw and grain yield were significantly affected by spray concentrations only while spray frequency had no significant effect. Maximum straw yield (7.54 t/ha) and total biomass (12.98 t/ha) was observed with three sprays of 0.5% ZnSO4 with an increase of about 40.98% and 40.6% respectively. Straw yield (Table 1) increased significantly for all concentrations ranging between 20.75% to 31.78%, 20% to 38.6% and 18.5% to 40.98% with one, two and three sprays respectively as compared to control. A significant increase was further observed in total biomass from 0.25% to 0.5% ZnSO4 ranging between 28.71% to 38.95% and 32.61% to 40.6% for two and three sprays respectively as compared to control. Application of 1% ZnSO4 was less effective in increasing total biomass (Table 2) as compared to other concentrations of ZnSO4 for all the spray frequencies. Among the treated plants, Minimum straw yield (6.34 t/ha) and total biomass (11.01 t/ha) were observed with three sprays of 1.0% ZnSO4.

There was significant increase in harvest index (Table 2) only when plants were treated with three sprays of 0.25% ZnSO4, other concentrations showed non-significant effect. Among the treated plants, maximum (an increase of 6.26% over control) harvest index was observed with three sprays of 0.25% ZnSO4 and minimum harvest index was observed with three spray of 0.5% ZnSO4.

Table 1: Effect of different concentrations of $ZnSO_4$ on grain and straw yield of rice genotype PD -12

Concentration of Zinc Sulfate	Grain Yield(t/ha)				Straw Yield(t/ha)			
	Stages of Zn Application				Stages of Zn Application			
	S1	S2	S3	Mean	S1	S2	S3	Mean
Control	3.79	3.99	3.84	3.87^A	5.21	5.50	5.34	5.35^A
0.25%	5.17	5.18	5.46	5.27^C	6.46	6.69	6.78	6.64^C
0.5%	5.39	5.41	5.43	5.41^D	6.88	7.41	7.54	7.28^E
0.75%	5.13	5.18	5.25	5.18^C	7.05	6.96	6.91	6.97^D
1.0%	4.87	4.79	4.66	4.77^B	6.66	6.42	6.34	6.47^B
Mean	4.87^a	4.91^a	4.93^a		6.45^a	6.59^b	6.58^b	

S1: One spray at 30 days after transplanting; S2: Two sprays, one each at 30 and 45 days after transplanting; S3: Three sprays, one each at 30, 45 and 60 days after transplanting **Values having same letters do not show significant differences at 5% level by Duncan test

Table 2: Effect of different concentrations of $ZnSO_4$ on biological yield and harvest index of rice genotype PD-12

Concentration of Zinc Sulfate	Biological Yield(t/ha)				Harvest Index (%)			
	Stages of Zn Application			Mean	Stages of Zn Application			Mean
	S1	S2	S3		S1	S2	S3	
Control	9.00	9.49	9.18	9.23^A	41.75	41.50	41.50	41.58^A
0.25%	11.63	11.88	12.24	11.92^C	43.75	43.25	44.00	43.67^B
0.5%	12.27	12.82	12.98	12.69^D	43.50	41.75	41.25	42.17^A
0.75%	12.18	12.14	12.16	12.16^C	41.25	42.25	42.50	42.00^A
1.0%	11.53	11.21	11.01	11.25^B	42.00	42.25	42.00	42.08^A
Mean	11.32^a	11.51^a	11.51^a		42.45^a	42.20^a	42.25^a	

S1: One spray at 30 days after transplanting; S2: Two sprays, one each at 30 and 45 days after transplanting; S3: Three sprays, one each at 30, 45 and 60 days after transplanting **Values having same letters do not show significant differences at 5% level by Duncan test

Total zinc uptake and Use efficiency

Total zinc uptake increased in the range of 38.1-62.62%, 36.06-73.23% and 35.35-79.35% with one two and three sprays, respectively as compared to control (Figure 1). Application of 0.5% $ZnSO_4$ spray concentration was found most effective in increasing total zinc uptake, under which zinc uptake increased by about 79.35% as compared to control while minimum increase in zinc uptake (35.35% over control) was observed with three sprays of 1% $ZnSO_4$.Application of different concentration of zinc substantially affected the efficiency indices. Agronomic efficiency was highest in plants which were treated with 0.25% of $ZnSO_4$ and afterward increasing concentrations of $ZnSO_4$ showed decreased efficiency. However, physiological efficiency was highest with the treatment of 0.25% $ZnSO_4$ and decreases upto the spray of 0.75% $ZnSO_4$ then increases when plants were sprayed with 1% of $ZnSO_4$.

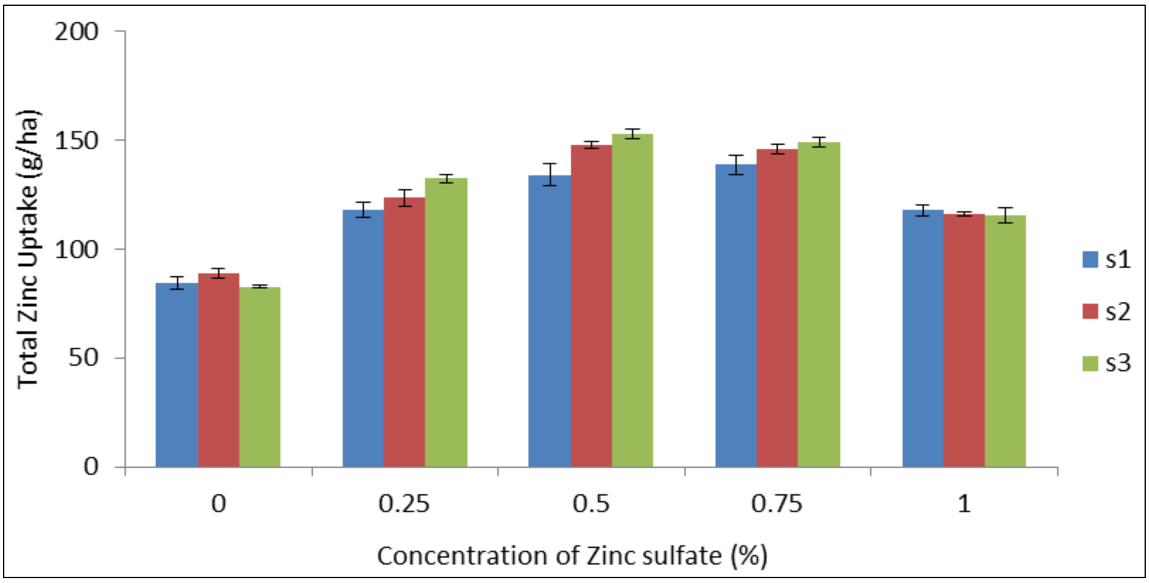

Fig 1: Effect of different concentrations of $ZnSO_4$ on total zinc uptake by rice

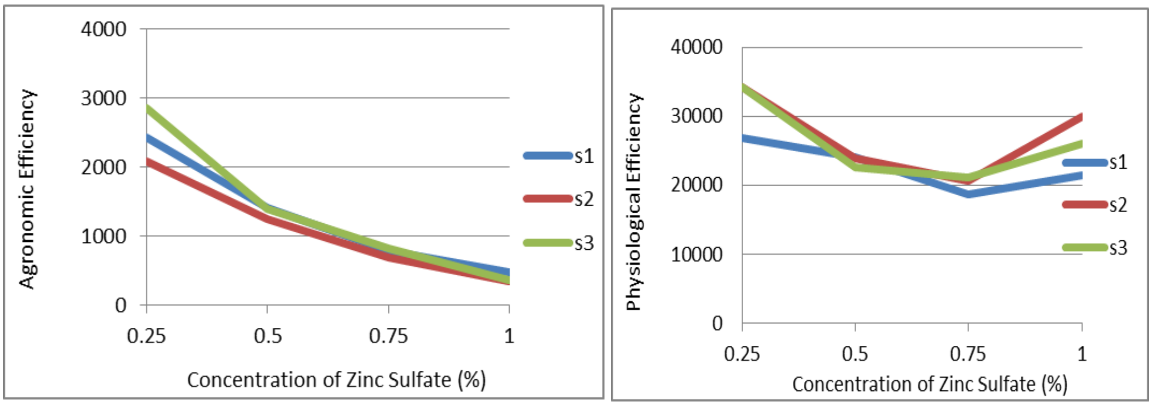

Fig 2: Effect of different concentrations of $ZnSO_4$ on Agronomic Efficiency (A) and Physiological Efficiency (B)

Discussion

Zinc being an essential micronutrient, its soil application along with N, P and K leads to better crop stand establishment, increased seed and seedling vigor, optimum tillering and thereby increasing the yield of the crops. Micronutrient uptake and transport to the edible parts of plants can be increased by fertilizer application to leaf. So, foliar application is much more efficient in grain Zn accumulation than the soil application (Jan *et al*., 2016) [12].In view of above, present study was conducted to evaluate the effect of different concentration of $ZnSO_4$on the yield of rice cultivar PD-12. Zinc foliar application significantly enhanced the grain and straw yield (Table no.1), biological yield and harvest index (Table no.2) of rice cultivar PD-12. Zinc is known to be involved in the synthesis of chlorophyll and also required by the enzymes which play important role in carbohydrate metabolism. Zinc is essential in the formation of auxins, which help with growth regulation and stem elongation. This might be the reason of high grain, straw and total biological yield of the plants which were treated with ZnSO4. Farooq *et al*., 2018 [9]; Shariatipour *et al*., 2020 [16]; Zulfiqar *et al*., 2021 [22] reported that Zn treatment improves the pollination and pollen tube development and increases number of fertile tillers, kernels per panicle, test weight and ultimately the grain yield. As sufficient zinc results in growth and high sink activity of the shoot apex that could explain the increased harvest index. Highest total Zn uptake was found when plants were treated with three sprays of 0.5% $ZnSO_4$. Zinc applied as a foliar application is readily absorbed by leaf epidermis, and after remobilization, it is transferred via phloem into developing seeds with the help of various transporter proteins. Zn foliar spray at the early reproductive stage readily translocates the Zn to the reproductive structure of the plant. With increasing concentration of $ZnSO_4$ agronomic efficiency decreased, whereas physiological efficiency showed discontinuous trend, as from 0.25% to 0.75% $ZnSO_4$ treatment the decrement was seen in agronomical efficiency but at 1% $ZnSO_4$ application there was rise in physiological efficiency showing the ability of a plant to transform Zn acquired from fertilizer into economic yield.

Conclusion

Differences in efficacy of different Zn concentrations with regard to yield and total zinc uptake were also apparent. The highest grain yield was noticed with the treatment of 0.25% $ZnSO_4$while high straw yield, total biological yield, zinc uptake was achieved when plants were sprayed with 0.5% $ZnSO_4$. These results suggest that Zn treatment in plants through foliar spray can be helpful to combat the several syndromes caused due to Zn deficiency. Moreover, there is need for more extensive studies on diverse types of soils and climatic conditions to validate these finding.

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