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Effect of zinc and sulfur on growth, yield and content of Zn & S in post harvest soil of rice (*Oryza sativa* L.)

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Abstract

A field experiment was conducted on the effect of Zn and S on growth, yield of rice and Zn & S content in post harvest soil in *khari*, 2024. Zinc and sulfur significantly enhanced plant growth parameters, grain, straw & biological yields of rice and improved Zn and S content in post harvest soil. Results indicated that combined use of 9kg Zn ha⁻¹ and 45kg S ha⁻¹ enhanced growth parameters. Maximum plant height (117.66 cm/plant), highest numbers of tillers per hill (25.94) in treatment Zn₉S₄₅ and maximum plant dry weight (4.66 g/plant) in treatment Zn₉S₃₀ were recorded at maturity. Combined use of 9 kg Zn and 30 kg S ha⁻¹ yielded significantly maximum grain yield (40.18 q/ha), straw yield (139.75q/ha) and biological yield (179.93 q/ha). Application of 45kg S ha⁻¹ with zinc levels exhibited antagonistic effect on grain, straw and biological yields. Zn & S synergistically influenced nutrients content in soil. Zinc 9kg ha⁻¹ and S45 kg ha⁻¹ had more zinc (0.97 mg/kg) as well as sulfur (15.19 mg/kg) content in post harvest rice soil.

Keywords: Rice, zinc, sulfur, combined use, growth, yield

1. Introduction

Zinc deficiency is one of the most widespread micronutrient issues in rice, often worsened by submerged conditions and high soil phosphorus levels that hinder zinc availability and mobility. The availability of zinc and sulfur in soils is highly influenced by management practices and soil properties such as pH, organic matter content and redox potential. It is a crucial micronutrient which is involved in enzymatic reactions, DNA transcription and auxin metabolism (such as IAA) and plays a vital role in reproductive development including pollen formation and seed setting (Alloway, 2008) [2]. Periodic assessment of soil test data suggests that Zn deficiency in soils of India is likely to increase from 49% to 63% by the year 2025 as most of the marginal soils brought under cultivation are showing Zn deficiency (Singh *et al.* 2006) [19]. However, a recent report of Shukla and Behera (2019) [16] indicated that the extent of Zn deficiency in Indian soil had declined from 48.8% in 1987-1999 to 36.5% in 2011-2017 due to the regular use of Zn fertilizers. Singh *et al.* (2016) [22] also reported that only 33.1% soils of various districts of Eastern Uttar Pradesh were deficient in Zn.

Sulfur is essential for amino acid and protein synthesis, enzyme activation and various metabolic functions (Blair & Lefroy, 1987) [3]. Its deficiency during early growth stages can severely limit tillering and yield potential.

Rice (*Oryza sativa* L.) is a staple food for more than half of the world's population over three billion people and is particularly critical in Asia where it stabilizes food security and economic stability. Globally, rice is cultivated on approximately 162.1 million hectares, producing around 746.6 million tonnes annually. India, a major rice-producing country, grows rice on about 51 million hectares and produces 147 million tonnes (USDA's *Rice Outlook* report) [23]. However, its national average productivity of 2.9 tonnes ha⁻¹ remains well below to its potential. This yield gap is due to several factors, particularly nutrients deficiency resulting from intensive farming, topsoil erosion, leaching and historically imbalanced fertilization practices that emphasize use of nitrogen over other essential nutrients such as zinc (Zn) and sulfur (S). This issue is especially pronounced in state like Uttar Pradesh where production of 21.74 million tonnes of rice and 6.5 million hectares in acreage (Agricultural Market Intelligence Centre, PJTSAU, February 2025) [1]. The adoption of high-yielding rice varieties and intensified cropping systems have increased

production but also led to significant nutrient depletion without adequate replenishment. On an average to produce one tonne of grain of high-yielding varieties of rice, removal of about 22 kg N, 7 kg P₂O₅, 32 kg K₂O, 5 kg MgO, 4 kg CaO, 1 kg S and 40g Zn from the soil occur (Chaudhary *et al.*, 2007) ^[4]. Although the physiological importance of these nutrients and their positive effects on yield when applied with NPK fertilizers are well documented. Combined impact of Zn and S on soil health, plant growth and yield in specific high-yielding rice varieties remains under-explored.

Samba Mahsuri (BPT-5204) is a semi-dwarf, medium-slender, high-quality rice cultivar widely grown in India which is suitable for both Kharif and Rabi seasons (with a 135-140 day duration). It offers resistance to neck blast and tolerance to gall midge with a yield potential of 5.5-6.0 t/ha (ICAR-IIRR, 2020) ^[10].

Keeping in view the importance of zinc and sulfur nutrients in crop physiology and ultimately in the economic yield of rice, the present field experiment was conducted in agro climatic region of Eastern Uttar Pradesh.

2. Materials and Methods

2.1 Experimental Site

A field experiment was conducted at the research farm of Department of Soil Science and Agricultural Chemistry, Naini Agricultural Institute, SHUATS, Prayagraj, U.P during kharif season, 2024. The Experimental site is situated at 25°44' N latitude, 81° 85' E longitude and at the altitude of 98 meter above the sea level. Prayagraj has a subtropical climate which experiences extremely hot summer 46°C-48°C and fairly cold winter 4°C-5°C, the relative humidity between 20 to 94 per cent and annual precipitation of about 1100 mm. During the rice cultivation period (July- October) temperature ranged from a maximum of 39.6-33.6 to minimum of 20-28°C. Relative humidity varied between 100 to 34%.

2.2 Experimental Setup

The experiment was carried out in factorial Randomized Block Design (F-RBD) of four levels each of sulfur S₀ (0 kg), S₁₅ (15kg), S₃₀ (30kg) & S₄₅ (45kg) as gypsum and zinc Zn₀ (0 kg), Zn₃ (3kg), Zn₆ (6kg) & Zn₉ (9kg) as ZnO. Total 16 treatments were replicated thrice.

The soil texture of experimental site was sandy loam with pH value of 7.11, electrical conductivity 0.30 dS/m⁻¹ (1:2.5 soil: water solution), organic carbon 0.32%, available nitrogen 230.70 kg ha⁻¹, available phosphorus 19.48 kg ha⁻¹, available potassium 195.00 kg ha⁻¹, sulfur 9.70 mg kg⁻¹ and extractable zinc 0.65 mg kg⁻¹.

A 25 days old two seedlings were transplanted on 22th July, 2024 in each hill at the spacing of 25 x 20cm. Recommended doses of nitrogen, phosphorus and potassium were applied through urea, di-ammonium phosphate and muriate of potash, respectively. Half of the nitrogen and full dose of phosphorus and potassium were applied at transplanting. Remaining half of nitrogen was top dressed in 2 equal splits i.e. 25% at maximum tillering and 25% at panicle initiation. Weeding was done manually at 30 and 60 days after transplanting (DAT) to reduce weed infestation, favor root and plant growth and to maintain the root zone aerobic. Crop was irrigated plot wise as and when required. All other agronomical practices were followed to protect the crop from insect and pests. Growth parameters such as plant height (cm plant⁻¹), plant oven dry weight (g plant⁻¹) and number of tillers hill⁻¹ were recorded at different physiological growth stages viz., at 30, 60 & 90 DAT. Five hills were earmarked randomly. Five plants (one plant from each tagged

hill) were randomly taken to record the plant height using meter scale and same were removed for plant dry weight. Plant samples were brought to laboratory, washed gently to remove the soil and other foreign materials. After air drying, plant samples were oven dried at 60°C ±2°C. At maturity crop was harvested plot wise, bundled and left for few days for drying. Dried crop bundles were weighed for their total biological yield and after threshing grain yield was recorded for a plot. Grain yield was subtracted from total biological yield to get the straw yield. Biological yield, grain yield and straw yields were expressed in term of qha⁻¹. Soil samples collected from each plot were processed and used to analyze available sulfur and extractable zinc following the standard procedures as described by Chesnin and Yien (1950) ^[5] and Lindsay and Norvell (1978) ^[12], respectively.

2.3 Statistical Analysis

All the data recorded were statistically analyzed to draw a valid conclusion following the procedure as outlined by Gomez and Gomez (1984) ^[7]. Significant differences between the mean of treatments were compared with the critical difference at P=0.05 level of significance.

3. Results and Discussion

3.1 Effect of Zinc and Sulfur levels conjugated with recommended dose of NPK on growth attributes of rice

The individual effect of zinc and sulfur levels conjugated with recommended dose of NPK on plant height at 30 and 90 DAT was found significant (Table 1). Maximum plant height 68.49, 113.10 cm and 68.33, 112.93 cm were recorded in Zn₉ and S₄₅ and minimum 60.63, 105.10 cm and 61.47, 104.44 cm were found in Zn₀ and S₀. The interaction effect of Zn & S was found non-significant. In early stage rice plants have underdeveloped roots, limiting simultaneous uptake of Zn and S. Hossain *et al.* (2019) ^[9] reported that the immobility of zinc in soil and the gradual mineralization of sulfur in flooded rice systems delayed any potential interaction effects on early growth parameters like plant height. Singh *et al.* (2018) ^[17] found that Zn and S application in rice improved yield and did not show a strong interaction effect on plant height at maturity. The effect of zinc and sulfur levels conjugated with recommended dose of NPK on plant height at 60 DAT was found significant. The maximum height 112.77 and 108.60 cm was found in Zn₉ and S₄₅ and minimum 97.33 and 98.86 cm in Zn₀ & S₀. The interaction effect of Zn & S was also found significant. Maximum height 123.30 cm found in Zn₉S₄₅ and minimum 88.11cm in Zn₀S₀. Fageria *et al.* (2011) ^[6] elucidated that Zn and S interaction peaked during tillering to panicle initiation (45-60 DAT) in rice, as both nutrients jointly enhanced biomass accumulation and stem elongation.

The individual effect of zinc and sulfur levels and their interaction conjugated with recommended dose of NPK on number of tillers per hill at 30 DAT was found non-significant (Table 2). At 60 and 90 DAT, the individual effect of Zn & S conjugated with recommended dose of NPK was found significant. The maximum number of tillers 23.81, 22.14 and 22.81, 21.21 in Zn₉ & S₄₅ and minimum 17.61, 16.38 and 19.00, 17.67 were observed in Zn₀ & S₀ at 60 and 90 DAT, respectively. At 90 DAT, a slight decline in tillers was observed relative to 60 DAT. This might be due to the decline in non-productive tillers at this stage attributed to carbon starvation in shaded lower tillers, leading to programmed cell death (Li *et al.*, 2019) ^[11] and (Ying *et al.*, 1998) ^[24]. Singh and Shivay (2016) ^[20] reported that sulfur and zinc individually improved tiller

formation under low N supply, but their interaction did not result in a statistically significant increase in tiller number compared to main effects.

The individual effect of zinc and sulfur levels conjugated with recommended dose of NPK on plant dry weight at 30,60 & 90 DAT was found significant (Table 3). Maximum 0.51, 2.21, 4.24g and 0.54, 2.20, 4.07g was recorded Zn₉ & S₄₅ and minimum 0.42, 1.68, 3.30g and 0.38, 1.60, 3.17g was recorded in Zn₀ & S₀. The interaction effect of Zn & S was found non-significant at all growth periods. The increase in dry weight under Zn and S treatments may be attributed to improve nutrient uptake efficiency, enzymatic activity and physiological processes which supported vigorous vegetative growth and sustained biomass production throughout the crop growth period. Ravi *et al.* (2022) [14] found that zinc fertilization at 10-20 kg ha⁻¹ improved straw yield by 20-33%, indicating higher dry matter accumulation.

3.2 Effect of Zinc and Sulfur levels conjugated with recommended dose of NPK on yields of rice

The individual effect of zinc and sulfur levels conjugated with recommended dose of NPK on grain, straw and biological yields of rice were found significant (Table 4, 5 & 6). Maximum yields 38.64, 127.64, 166.27 q/ha and 34.60, 125.39, 159.99 q/ha were recorded in individual Zn₉ & S₃₀. Minimum 26.63, 98.75, 125.38 q/ha and 30.57, 107.30, 137.86 q/ha was found in Zn₀ & S₀. Application of 45 kg S ha⁻¹ with Zn levels adversely affected yields. This result is in conformity with those of Singh & Shivay (2016) [21] who stated that S application beyond 30 kg ha⁻¹ lead to diminishing returns due to nutrient antagonism, S-induced Zn deficiency.

The interaction effect of Zn and S on biological, grain and straw yields was found significant. The maximum yields 40.18,

139.75, 179.93 q/ha was recorded with Zn₉S₃₀. Minimum 24.02, 86.83, 110.84 q/ha was recorded in Zn₀S₀. Shivay and Kumar (2015) [15] explained that Zn₉S₃₀ was an optimal combination enhancing straw yield through improved Zn translocation and sulfur-induced enzymatic activity. Therefore, treatment Zn₉S₃₀ was found to be most effective for maximizing straw yield in rice. (Hawkesford, & De Kok., 2014) [8] who stated that optimum Zn-S combination improves grain yield through enhanced photosynthate and translocation and extended grain filling though excessive application may reduce efficiency by 10-12%.

3.3 Effect of Zinc and Sulfur levels conjugated with recommended dose of NPK on Zn & S content in post-harvest rice soil

The effect of zinc and sulfur levels conjugated with recommended dose of NPK significantly influenced extractable zinc in post harvest soil (Table 7). Maximum 0.95 and 0.85 mg Zn kg⁻¹ was found in Zn₉ & S₄₅. Minimum 0.70 and 0.77 mg Zn kg⁻¹ was recorded in Zn₀ & S₀. The interaction effect of Zn and S was found non-significant. However, Zn₉ S₄₅ showed highest 0.97 mg Zn kg⁻¹ in post harvest rice soil. Nayak *et al.* (2018) [13] also observed that extractable Zn reached 0.95 mg kg⁻¹ under high Zn and S treatment (Zn₈+S₄₅) and sulfur played a crucial role in improving Zn solubility.

The effect of zinc and sulfur levels conjugated with recommended dose of NPK on available sulfur in post harvest soil was found significant (Table 8). Maximum 14.53 and 12.62 mg S kg⁻¹ was recorded in Zn₉ and S₄₅. Minimum 9.28 and 11.53 mg S kg⁻¹ was found in Zn₀ & S₀. The interaction effect of Zn and S was non-significant. Singh *et al.* (2018) [18] also observed that conjugated use of S and Zn enhanced S content in rice by improving retention and reducing leaching loss of sulphate-S.

Table 1: Effect of zinc and sulfur levels conjugated with recommended dose of NPK on plant height (cm) at different days after transplanting of rice

Zinc Levels (kg/ha)	Sulfur Levels (kg/ha)														
	Plant height (cm/plant)														
	30 DAT					60 DAT					90 DAT				
	S ₀	S ₁₅	S ₃₀	S ₄₅	Mean	S ₀	S ₁₅	S ₃₀	S ₄₅	Mean	S ₀	S ₁₅	S ₃₀	S ₄₅	Mean
Zn ₀	57.00	59.00	61.00	65.55	60.63	88.11	96.00	103.44	101.77	97.33	99.33	104.44	106.88	109.77	105.10
Zn ₃	62.00	62.77	63.88	68.33	64.24	91.00	98.55	105.22	102.00	99.19	103.22	110.00	107.55	110.44	107.80
Zn ₆	62.66	64.00	65.22	69.11	65.24	107.33	102.55	108.55	107.33	106.44	105.88	107.55	108.11	113.88	108.85
Zn ₉	64.22	65.00	74.44	70.33	68.48	109.00	107.22	111.55	123.30	112.77	109.33	112.00	113.44	117.66	113.10
Mean	61.47	62.69	66.13	68.33	-	98.86	101.08	107.19	108.60	-	104.44	108.49	108.99	112.93	-
		F-Test	S.Em±	CD(5%)			F-Test	S.Em±	CD(5%)			F-Test	S.Em±	CD(5%)	
Zinc		S	2.51	5.12			S	1.92	3.79			S	2.07	4.23	
Sulfur		S	2.51	5.12			S	1.92	3.79			S	2.07	4.23	
Zn x S		NS	5.01	NA			S	3.84	7.85			NS	4.14	NA	

Table 2: Effect of Zinc and Sulfur levels conjugated with recommended dose of NPK on number of tillers (per hill) at different days after transplanting of rice

Zinc levels (kg/ha)	Sulfur levels (kg/ha)														
	Number of tillers (per hill)														
	30 DAT					60 DAT					90 DAT				
	S ₀	S ₁₅	S ₃₀	S ₄₅	Mean	S ₀	S ₁₅	S ₃₀	S ₄₅	Mean	S ₀	S ₁₅	S ₃₀	S ₄₅	Mean
Zn ₀	7.78	8.00	8.33	8.44	8.13	17.00	14.11	17.33	19.00	17.61	15.81	16.91	16.12	17.67	16.38
Zn ₃	7.56	8.22	8.57	8.54	8.22	18.00	18.67	19.22	21.11	19.25	16.74	17.36	17.88	19.63	17.90
Zn ₆	7.11	8.11	8.58	9.67	8.36	20.11	20.44	23.00	23.22	21.69	18.70	19.01	21.39	21.60	20.18
Zn ₉	8.00	8.56	9.11	10.11	8.94	20.89	22.11	24.33	27.89	23.81	19.43	20.56	22.63	25.94	22.14
Mean	7.61	8.22	8.64	9.19	-	19.00	19.58	20.97	22.81	-	17.67	18.21	19.51	21.21	-
		F-test	S.Em±	CD(5%)			F-test	S.Em±	CD(5%)			F-test	S.Em±	CD(5%)	
Zinc		NS	0.76	NA			S	1.10	2.25			S	0.82	1.68	
Sulfur		NS	0.76	NA			S	1.10	2.25			S	0.82	1.68	
Zn x S		NS	1.51	NA			NS	2.20	NA			NS	1.64	NA	

Table 3: Effect of Zinc and Sulfur levels conjugated with recommended dose of NPK on plant dry weight (g) at different days after transplanting of rice

Zinc levels (kg/ha)	Sulfur levels (kg/ha)														
	Plant dry weight (g)														
	30 DAT					60 DAT					90 DAT				
	S ₀	S ₁₅	S ₃₀	S ₄₅	Mean	S ₀	S ₁₅	S ₃₀	S ₄₅	Mean	S ₀	S ₁₅	S ₃₀	S ₄₅	Mean
Zn ₀	0.31	0.42	0.45	0.51	0.42	1.47	1.68	1.69	1.89	1.68	2.54	3.10	3.79	3.79	3.30
Zn ₃	0.38	0.44	0.47	0.53	0.45	1.54	1.62	1.89	2.01	1.76	3.11	3.67	3.58	3.67	3.50
Zn ₆	0.41	0.46	0.51	0.54	0.48	1.69	1.90	2.26	2.34	2.04	3.67	3.75	4.07	4.20	3.92
Zn ₉	0.44	0.49	0.55	0.58	0.51	1.70	2.16	2.45	2.56	2.21	3.39	4.28	4.66	4.65	4.24
Mean	0.38	0.45	0.49	0.54	-	1.60	1.84	2.07	2.20	-	3.17	3.7	4.02	4.07	-
		F-test	S.Em±	CD(5%)			F-test	S.Em±	CD(5%)			F-test	S.Em±	CD(5%)	
Zinc		S	0.03	0.06			S	0.23	0.47			S	0.26	0.54	
Sulfur		S	0.03	0.06			S	0.23	0.47			S	0.26	0.54	
Zn x S		NS	0.06	NA			NS	0.46	NA			NS	0.53	NA	

Table 4: Effect of Zinc and Sulfur levels conjugated with recommended dose of NPK on grain yield (q/ha)

Zinc levels (kg/ha)	Sulfur levels (kg/ha)				
	Grain Yield (q ha ⁻¹)				
	S ₀	S ₁₅	S ₃₀	S ₄₅	Mean
Zn ₀	24.2	25.14	30.94	26.43	26.63
Zn ₃	27.75	29.93	32.19	30.19	30.01
Zn ₆	33.86	33.97	35.07	34.67	34.39
Zn ₉	36.65	38.49	40.18	39.22	38.64
Mean	30.57	31.88	34.60	32.63	-
		F-test	S.Em±	CD(5%)	
Zinc		S	0.48	0.98	
Sulfur		S	0.48	0.98	
Zn x S		S	0.96	1.96	

Table 5: Effect of Zinc and Sulfur levels conjugated with recommended dose of NPK on straw yield (q/ha)

Zinc levels (kg/ha)	Sulfur levels (kg/ha)				
	Straw yield (q/ha)				
	S ₀	S ₁₅	S ₃₀	S ₄₅	Mean
Zn ₀	86.83	93.00	101.02	114.17	98.75
Zn ₃	104.02	109.75	122.72	115.11	112.90
Zn ₆	111.57	116.80	138.09	117.63	121.02
Zn ₉	126.77	127.31	139.75	116.72	127.64
Mean	107.30	111.72	125.39	115.91	-
		F-test	S.Em±	CD(5%)	
Zinc		S	2.99	6.10	
Sulfur		S	2.99	6.10	
Zn x S		S	5.97	12.19	

Table 6: Effect of Zinc and Sulfur levels conjugated with recommended dose of NPK on total biological yield (q/ha)

Zinc levels (kg/ha)	Sulfur levels (kg/ha)				
	Total biological yield (q/ha)				
	S ₀	S ₁₅	S ₃₀	S ₄₅	Mean
Zn ₀	110.84	118.14	131.95	140.59	125.38
Zn ₃	131.77	139.68	154.90	145.29	142.91
Zn ₆	145.43	150.77	173.16	152.30	155.41
Zn ₉	163.42	165.80	179.93	155.94	166.27
Mean	137.86	143.60	159.99	148.53	-
		F-test	S.Em±	CD(5%)	
Zinc		S	3.07	6.28	
Sulfur		S	3.07	6.28	
Zn x S		S	6.15	12.55	

Table 7: Effect of Zinc and Sulfur levels conjugated with recommended dose of NPK on extractable zinc (mg/kg) in post harvest rice soil

Zinc levels (kg/ha)	Sulfur levels (kg/ha)				
	Extractable Zinc(mg kg ⁻¹)				
	S ₀	S ₁₅	S ₃₀	S ₄₅	Mean
Zn ₀	0.67	0.68	0.71	0.73	0.70
Zn ₃	0.73	0.74	0.76	0.80	0.76
Zn ₆	0.78	0.82	0.87	0.91	0.85
Zn ₉	0.91	0.94	0.96	0.97	0.95
Mean	0.77	0.80	0.83	0.85	-
		F-test	S.Em±	CD(5%)	
Zinc		S	0.02	0.04	
Sulfur		S	0.02	0.04	
Zn x S		NS	0.04	NA	

Table 8: Effect of Zinc and Sulfur levels conjugated with recommended dose of NPK on available sulfur (mg/kg) in post harvest rice soil

Zinc levels (kg/ha)	Sulfur levels (kg/ha)				
	Available Sulfur(mg kg ⁻¹)				
	S ₀	S ₁₅	S ₃₀	S ₄₅	Mean
Zn ₀	8.85	9.22	9.49	9.55	9.28
Zn ₃	10.34	11.01	11.13	11.82	11.08
Zn ₆	12.87	13.08	13.49	13.92	13.34
Zn ₉	14.07	14.40	14.47	15.19	14.53
Mean	11.53	11.93	12.15	12.62	-
		F-test	S.Em±	CD(5%)	
Zinc		S	0.17	0.35	
Sulfur		S	0.17	0.35	
Zn x S		NS	0.34	NA	

4. Conclusion

Based on the results, it was concluded that different levels of zinc and sulfur conjugated with recommended dose of NPK significantly influenced the zinc and sulfur content in post harvest soil, growth and yield of rice. Among the treatments, application of 9 kg Zn as well as 45 kg S ha⁻¹ individually and in combination exhibited their significance in enhancing the growth attributes and zinc & sulfur content in post harvest soil of rice. Use of zinc @ 9 kg and sulfur 30 kg ha⁻¹ showed its significance in enhancing the production of grain, straw and biological yields and these were decreased beyond 30 kg sulfur ha⁻¹ either alone or in combination with levels of zinc.

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