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Economics of zinc (Zn) fertilizer application on rice (*Oryza sativa* L.) crop under different water and soil environments

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ABSTRACT

A field experiment was conducted in an acid inceptisol of Bhubaneswar in wet season (*Kharif*) 2021 receiving high rainfall (1500 mm) and low available Zn (0.47 mg kg^{-1}). Results of the field experiment revealed that soil application of Zn 5 kg ha^{-1} ($ZnSO_4.7H_2O$ 25 kg ha^{-1}) at last ploughing along with soil test based fertilizer dose of 100:40:50 kg N, P_2O_5, K_2O ha^{-1} was optimum considering grain yield (49.2 q ha^{-1}), net return (Rs 41.2 thousand ha^{-1}) and net B:C ratio (1.68). Secondary data analysis from published research articles revealed that yield improvement due to zinc fertilizer application was highest (19.8%) for the aerobic soil followed by acidic soil (16.1%) and high pH soil (10.3%). Improvement in net return was also highest (64.7%) for aerobic soil, followed by acidic soil and high pH soil. Overall mean across the three soil water environments revealed that soil application of 5 kg zinc through water soluble $ZnSO_4.7H_2O$ improved grain yield, net return and net B:C ratio by 13.6%, 27.2% and 25.3%, respectively. So, Zn fertilizer application is needed most in deficient aerobic soil followed by acidic soils of high rainfall areas, and high pH soils in rice cultivation.

Key Words: *Aerobic rice, Acidic soil, Cost of cultivation, Net B:C ratio and Net return*

In India, only one percent of farmers use optimal inputs (Bedi and Prabhakar, 2023). Rice is the most important food crop in Asia and receives good amount of N followed by P and K. However, Zn is the most important micro-nutrient deficiency and often overlooked in spite of the fact that it causes significant yield and economic loss (Rautaray and Sucharita, 2023). An IRRI survey of on-farm experiments in six countries reported that N was the most deficient nutrient followed by P and K with equal second in importance, while Zn and S were equal third in importance (Alloway, 2008). In India, it is considered as the fourth important nutrient limiting crop yield after N, P and K (Arunachalam *et al.*, 2013). Among the micronutrients, zinc (Zn) deficiency is the most prominent in tropical rice. Area under Zn deficiency is likely to increase from 49% to 63% by the year 2025 as most of the marginal soils brought under cultivation have such problem (Arunachalam *et al.*, 2013). Indian soils are the most deficient in Zn due to intensive cereal-cereal cropping system. Soil health mapping across 30 districts of Odisha revealed that 42% areas were Zn deficient. The districts like Bolangir, Sambalpur, Kalahandi and Bhadrak were prominently deficient in Zn due to continuous and intensive rice-rice cropping system.

Causes of Zn deficiency can be grouped as soil related problems, water related problems and crop management related problems. Soil related problems include (a) high soil pH, a prominent factor adversely affecting Zn availability in alkali soils, alkaline and (Dwivedi and Srivastava, 2014) and saline soils (For each unit rise in soil pH, there is 100 times decline in Zn availability) (b) reduced soil health under lowland conditions increases availability of antagonistic elements such as P, Fe, and Mn leading to suppression of Zn availability (Sucharita *et al.*, 2023) in China, Japan, India, Pakistan, Bangladesh, Nepal, Sri Lanka, The Philippines, The USA and Colombia. Water related problems include Zn deficiency in water stress situation due to low solubility and diffusion of Zn in soil in rainfed uplands in Cerrado of Brazil (Alloway, 2008), aerobic rice growing environments and dry direct seeded rice; irrigation water rich in antagonistic elements interfere in Zn availability. Lastly, crop management related problems include low use of organic fertilizers and manures, poor residue recycling and intensive cropping causes deficiency of Zn and Fe (Nadeem and Farooq, 2019).

Sub-optimal Zn content in grain may be linked to death of 800,000 people in the World, mainly children at the age of below 5 years. Health related complications due to Zn deficiency is responsible for this. Also, health of 2 billion people is affected due to Zn deficiency (Waqeel and Khan, 2022). Severe health complications (defective immune system, physical growth, learning capabilities, risk of infections, damage to DNA and cancer) are associated with Zn deficiencies. Also, such people are susceptible to mental lethargy, acrodermatitis and infertility. Over 30% of the global population is Zn-deficient. This issue arose by crop production on infertile lands and/or by the excessive consumption of low Zn rice (Mao *et al.,* 2014). Implications of Zn deficiency in plants include susceptibility to diseases, low photosynthesis and growth rate, and fewer tillers and grains per panicle. This leads to low grain and straw yield, and finally low net return. Low return results in poor resource use efficiency of applied fertilizers, irrigation water, plant protection chemicals, machineries and labour input. When available Zn in soil is limiting, additional application of other inputs is a waste until it is corrected first. Considering the importance of Zn on human health and rice crop productivity, it is important to study the economics of Zn fertilizer application in rice crop.

MATERIAL AND METHODS

This study consists of two parts. The first part consists of field experiment conducted in research farm. The second part consists of collection and analysis of data from research publications regarding economics of Zn fertilizer application on rice crop in different water and soil environments.

A. Field Experiment

The study was conducted in *Kharif* 2021 at the E Block of Central Farm in Regional Research and Technology Transfer Station, OUAT, Bhubaneswar, India. It lies at 20°15" N latitude, 85°55" E longitude and at an altitude of 25.9 m above the mean sea level. The experimental site belongs to a medium land irrigated with tube well. Intensive rice-vegetable cropping sequence was followed in last 5 years. The soil of experiment site was acidic (pH 5.4) sandy loam (69% sand, 16% silt and 15% clay). Available N (155.4 kg ha^{-1}), K (82.1 kg ha^{-1}) and Zn (0.47 mg kg^{-1}) status was low while organic carbon (0.61%) and available P (10.3 kg ha^{-1}) was medium.

The experiment was laid out in a randomized block design with 3 replications. The gross and net plot sizes were 5m×4m and 4.2 m x 3.6 m, respectively. There were 8 treatments; T_1: Control (No Zn), T_2: Soil application of Zn 2.5 kg ha^{-1}, T_3: Soil application of Zn 2.5 kg ha^{-1} + foliar spray with 0.1% Zn at 25 days after transplanting (DAT), T_4: Soil application of Zn 5 kg ha^{-1}, T_5: Soil application of Zn at 5 kg ha^{-1} + foliar spray with 0.1% Zn at 25 DAT, T_6: One foliar spray with 0.1% Zn at 25 DAT, T_7: Two foliar spray with 0.1% Zn at 25 and 50 DAT, and T_8: Seedling root dip with 2% ZnO. The source of fertilizer for soil application and foliar spray was fertilizer grade $ZnSO_4.7H_2O$ containing 20% Zn. For seedling root drip, fertilizer grade ZnO was used containing 80% Zn. Seedling root dip with 2% Zn was done by preparing 2.5% ZnO suspension (500 g ZnO in 20 litres water ha^{-1}) and dipping the roots of uprooted seedling for 30 minutes. For foliar spray with 0.1% Zn, solution of 0.5% $ZnSO_4.7H_2O$ was prepared by dissolving at 2500 g in 500 litre water ha^{-1}.

Rice variety 'Binadhan 11' was used in the experiment. It is developed by Bangladesh Institute of Nuclear Agriculture from Indonesian variety Ciherang, and introduced by IRRI under 'Seeds without border' programme. Seedlings were raised in wet nursery beds and transplanted on 8 August using 25days old seedlings at a spacing of 20 cm × 10cm with 2 seedlings hill^{-1}. Considering the soil test-based fertilizer requirement, 100 kg N, 40 kg P_2O_5 and 50 kg K_2O ha^{-1} was applied uniformly using diammonium phosphate, urea, and muriate of potash. The plots were irrigated as and when necessary to maintain standing water in the range of 3 to 5cm depth. However, the field was drained to saturation before applying fertilizer and shallow irrigation was given two days after it to maintain a submerged condition.

The economics of production for different treatments were worked per ha taking into account the cost of various inputs as well as the value of the produce as per the prevailing market price. The cost of fertilizer grade $ZnSO_4.7H_2O$ and ZnO were Rs75 and Rs125 kg^{-1}, respectively. Labor cost was Rs 315 d^{-1}. Gross return was calculated considering Minimum Support Price for paddy for the year 2021 as Rs

1940 q^{-1} and the local price for straw as Rs100 q^{-1}. The net profit was calculated by deducting the cost of cultivation from gross income (Rs ha^{-1}). The B:C ratio was worked out as net return divided by the cost of cultivation. Analysis of variance was applied for statistical analysis. Significance of treatments was tested by F-test and the Critical Difference (CD) was calculated at 5% probability.

B. Secondary data from published research papers

Data regarding economics of zinc fertilizer application on rice crop was collected from published paperes in google scholar, google search and J-Gate. A total of 19 research papers were used for this analysis. Soil application of zinc at 5 kg ha^{-1} through $ZnSO_4.7H_2O$ was the most common method of Zn application in these studies. Recommended dose of N, P and K fertilizers (NPK) is widely adopted by farmers. So, this practice (NPK) was compared with the NPK with Zn fertilizer application at 5 kg ha^{-1} (NPK+Zn). The 18 samples were further divided into three groups considering the associated problems related to water and soil. These are (a) acidic soils of high rainfall region promoting leaching loss and reduced soil condition for a major part of crop growth (8 research papers) (b) High pH Alkali, alkaline and calcic soils under irrigated condition (7 research papers), and (c) Aerobic rice and dry direct seeded rice (3 research papers).

RESULTS AND DISCUSSION

A. Field Experiment

Grain yield is a function of interaction of the three yield components in rice crop viz., panicle number m^{-2}, grains $panicle^{-1}$, and 1000 grain weight. All these parameters were highest under the soil application of Zn at 5 kg ha^{-1} + foliar spray with 0.1% Zn at 25 DAT followed by the soil application of Zn at 5 kg ha^{-1}. This has led to the highest grain yield of 49.4 q ha^{-1} (Table 1) under the soil application of Zn 5 kg ha^{-1} + foliar spray with 0.1% Zn at 25 DAT closely followed by the soil application of Zn 5 kg ha^{-1} (49.2 q ha^{-1}). Soil application of water-soluble Zn at 5 kg ha^{-1} has improved panicle number, grains panicle, and 1000 grain weight due to more dry matter accumulation and creation of source potential. Application of Zn improved root growth and there by mobilized plant nutrients in soil and finally increased grain yield of rice. Role of Zn fertilizer application in improving grain yield in deficient soil is reported Dwivedi and Srivastava, 2014; Rama Lakshmi *et al.*, 2017.

An agronomic practice is recommended for adoption if it is economic, and ecologically sound. Farmers mostly look for net return, easiness in implementation of a technology and least risk involvement. Maximum net return of Rs 41.2 thousand ha^{-1} and B:C ratio of 0.68 was noted under soil application of Zn 5 kg ha^{-1} closely followed by the soil application of Zn 5 kg ha^{-1}+ foliar spray with 0.1% Zn at 25 DAT (net return of Rs 41.1thousand ha^{-1} and B:C ratio of 0.68). Similar results are reported by Gill and Walia (2013). These two treatments were followed by soil application of Zn at a lower rate of 2.5 kg ha^{-1} with or without foliar spray. Alleviation of Zn deficiency with the application Zn fertilizer helped in increasing yield, and thereby the net return. No Zn application (Control) had lowest net return (Rs 29.8 thousand ha^{-1}) and B:C ratio (0.51). Foliar spray and seedling root dip were moderately effective in improving net return. for the treatment Two times foliar spray of 0.5% $ZnSO_4$, net return was Rs 34.8 thousand with benefit: cost ratio of 0.63. Hashim *et al.* (2021) reported a net return of Rs 67.9 thousand ha^{-1} and benefit: cost ratio as 2.41 with 3 times spray of 0.5% $ZnSO_4$.

Regarding data on net rupees per rupee invested on zinc fertilizer, prominently highest value 17.54 was noted under the treatment of seedling root dip with 2% Zn involving additional investment of Rs 378 ha^{-1}. So, poor farmers with investment limitation may opt for seedling root dip treatment. Some farmers in Pakistan are adopting such practice. This economic practice is especially useful in situations in which zinc availability is a problem for initial few weeks after transplanting due to soil constraints and/or high available phosphorous with the basal P application. However, after initial few weeks, soil should supply zinc to plants for getting optimum yields. For soils with high pH and other constraints in which zinc nutrition to rice plant is a problem, foliar spray is good option.

B. Secondary data from published research papers

Based on data from published research work on Zn fertilizer application on rice crop by different

Table 1. Yield and economics as influenced by scheduling of zinc fertilizer application

Treatments	Grain yield (q/ha)	Gross return (thousand Rs ha^{-1})	Net Return (thousand Rs ha^{-1})	Net B:C ratio	Rs ha^{-1} invested in Zn application	Net Rs/Rupee invested on Zn
NPK (No Zn)	42.4	87.8	29.8	0.51	-	-
Soil application of Zn 2.5 kg ha^{-1}	46.7	96.5	37.3	0.63	1253	5.94
Soil application of Zn 2.5 kg ha^{-1} + Foliar spray with 0.1% Zn at 25 DAT	47.6	98.3	38.6	0.65	1756	4.99
Soil application of Zn 5 kg ha^{-1}	49.2	101.4	41.2	0.68	2190	5.18
Soil application of Zn at 5 kg ha^{-1}+ Foliar spray with 0.1% Zn at 25 DAT	49.4	101.8	41.1	0.68	2693	4.2
One Foliar spray with 0.5% Zn at 25 DAT	44.2	91.5	33	0.56	503	6.39
Two Foliar spray with 0.1% Zn at 25 and 50 DAT	45.4	93.9	34.8	0.63	1006	5
Seedling root dip with 2% Zn	45.9	94.8	36.4	0.62	378	17.54
CD (P=0.05)	1.7	2.8	2.4	-	-	-

authors (mentioned in the Tables 2a, 2b and 2c), soil application of Zn 5 kg ha^{-1} along with the recommended fertilizer (NPK+Zn) is most common. So, comparison was made between this improved practice (NPK+Zn) with the common practice of application of recommended fertilizer alone (NPK).

(a) Acidic soils of high rainfall region promoting reduced soil condition for a major part of crop growth

In acidic soils of high rainfall regions, significant amount of zinc is lost due to leaching. Prolonged waterlogging in wet season and continuous use of NPK fertilizers over the yeas leads to Zn deficiency. Application of Zn 5 kg ha^{-1} has improved rice grain yield by 4.9% to 34.5% with a mean of 16.1% (Table 2a). This has resulted in increase in net return in the range of 33.7% to 89.8% with a mean of 42.2% and B:C ratio of 71.4%.

(b) Alkali, alkaline and calcic soils with high pH under irrigated condition

High soil pH is the constraint for Zn availability in alkali, alkaline and calcic soils. First symptom of Zn deficiency in rice crop was diagnosed in calcic soil of Terai region in India. Zinc fertilizer application improved rice grain yield in the range of 4.0% to 24.2% with a mean of 10.3% (Table 2 b). This has helped in increasing net return in the range of 8.6% to 48.6% with a mean of 18.7%. This is also reflected in mean increase in B:C ratio (10.9%).

(c) Aerobic rice and dry direct seeded rice

Due to water scarcity, alternative method rice cultivation such as aerobic rice and dry direct seeded rice is being promoted. However, moisture stress environment aggravates the problem of Zn solubility, mobility from soil to root via diffusion and the strength of transpiration pull due to low transpiration rate. So, Zn nutrition management is getting attention in addition to weeds, pathogens and physiological stress in this alternate method of rice cultivation. In this review, there was mean increase in grain yield by 19.8%, net return by 64.7% and net B:C ratio by 56.7% (Table 2 c).

(d) Comparison among three soil water environments

Yield improvement due to Zn fertilizer application was the highest (19.8%) for the aerobic soil. This was followed by acidic soil (16.1%) and

Table 2 (a) Yield, net return and B:C ratio as influenced by Zn fertilizer application in acidic soils of high rainfall region

Grain yield (q ha		% increase	Net Return		% increase	B:C ratio		% increase	Reference
NPK	NPK+Zn		NPK	NPK+Zn		NPK	NPK+Zn	NPK	
42.4	49.2	16.1	29.8	41.2	38.1	0.51	0.68	34.1	Sucharita and Rautaray, 2023
40.3	42.8	6.2	-	-	-	-	-	-	Parida P, 2021
68	76.3	12.2	37.3	55.3	48.5	0.31	0.45	47.2	Afrin *et al.* , 2022
26.4	35.5	34.5	7.8	14.7	89.8	0.04	0.91	2174.9	Kandali *et al.* , 2015
32.2	39.6	23	57.1	76.4	33.7	1.27	1.6	26	Mondal, R *et al.* , 2020
43.5	50.7	16.6	-	-	-	-	-	-	Kumar *et al.* , 2022
47.4	49.7	4.9	-	-	-	-	-	-	Majumder *et al.* , 2023
40.2	47.4	17.9	-	-	-	-	-	-	Singh *et al.* , 2018
Mean									
42.4	49.2	16.1	32.9	46.9	42.2	0.5	0.9	71.4	

Table 2 (b) .Yield, net return and net B:C ratio as influenced by zinc fertilizer application in high pH soil under irrigated condition

Grain yield (q ha		% increase	Net Return (000		% increase	Net B:C ratio		% increase	Reference
NPK	NPK+Zn		NPK	NPK+Zn		NPK	NPK+Zn	NPK	
40.5	42.1	4	60.9	75.9	24.6	1.32	1.23	-6.8	Nayak et al, 2022
44.2	51.7	17	49.6	61.7	24.3	1.54	1.88	22.1	Singh and Shivay, 2015
41.7	46.2	10.8	41.8	51.1	22.3	1.4	1.58	12.9	Prajapati et al, 2022
35.3	43.9	24.2	27.7	41.2	48.6	0.65	0.88	35.4	Regar et al, 2022
40.9	43.7	6.8	74.6	84.2	12.9	1.38	1.53	10.9	Ghasal et al, 2015
47	49.7	5.7	64.4	69.9	8.6	1.13	1.2	6.2	Shah et al., 2023
57.8	61.7	6.8	53.8	58.6	9	1.51	1.6	6	Prakashya et al., 2019
Mean									
43.9	48.4	10.3	53.2	63.2	18.7	1.28	1.41	10.9	

lowest with the high pH conditions of alkali, alkaline and calcic soil (10.3%). The lowest yield improvement with the high pH soil was due to improvement of soil pH after flooding. For each unit fall in soil pH, 100-fold increase in Zn availability is known. Highest yield improvement with the aerobic rice might be due enhanced probability of close root contact with the fertilizer and/or improved diffusion and mass flow of Zn^{+2} in soil. Such probability is high when soil moisture condition is favourable after irrigation or rainfall. Also, improved root growth and plant health with zinc fertilizer application might have improved yield. Increase in net return followed the same trend as grain yield. Highest net return (64.7%) was for the aerobic soil, followed by acidic soil and lowest with the high pH soils. Overall mean across the three soil water environments revealed that soil application of 5 kg zinc improved grain yield, net return and B:C ratio by 13.6%, 27.2% and 25.3%, respectively (Table 2 d).

Thus, zinc fertilizer application is needed in deficit soils, most importantly for aerobic rice cultivation, followed by rice grown under acidic soils of high rainfall region, and irrigated rice under high pH soils. Seedling root dip is a low cost technology for transplanted rice crop, if zinc availability in soil is expected to improve after few weeks of transplanting. For problem soils, hindering zinc solubility and mobility, foliar spray is the option.

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Table 2 (c). Yield, net return and net B:C ratio as influenced by zinc fertilizer application in aerobic rice and dry direct seeded rice

Grain yield (q ha-1)		% increase	Net Return (000 Rs ha-1)		% increase	Net B:C ratio		% increase	Reference
NPK	NPK+Zn		NPK	NPK+ Zn		NPK	NPK+Zn	NPK	
32.2	35.5	10.2	15.5	20	29.5	0.48	0.61	27.1	Singh *et al.* , 2018
22.86	31.54	38	16	31.8	98.8	0.49	0.91	85.7	Kumari *et al.* , 2019
33	38.42	16.4	-	-	-	-	-	-	Mondal, B *et al.* , 2020
Mean									
29.4	*35.2*	*19.8*	*15.7*	*25.9*	*64.7*	*0.49*	*0.76*	*56.7*	

Table 2 (d). Mean yield, net return and net B:C ratio as influenced by zinc fertilizer application irrespective of water and soil environment

Environments	Grain yield (q/ha)		% increase	Net Return (000Rs/ha)		% increase	Net B:C ratio		% increase
	NPK	NPK+Zn		NPK	NPK+Zn		NPK	NPK+Zn	NPK
Acidic soils	42.4	49.2	16.1	32.9	46.9	42.2	0.5	0.9	71.4
High pH Soils	43.9	48.4	10.3	53.2	63.2	18.7	1.28	1.41	10.9
Aerobic soil	29.4	35.2	19.8	15.7	25.9	64.7	0.49	0.76	56.7
Mean	*40.87*	*46.42*	*13.6*	*41.3*	*52.5*	*27.2*	*0.93*	*1.16*	*25.3*

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