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ORIGINAL ARTICLE

A Study on Management Protocol of Zn in Conventional Rice under Gangetic Alluvial Soils of West Bengal

Manish Kumar[1], Ritesh Kundu*[1], Gora Chand Hazra and Samrat Adhikary[1]
[1] Bidhan Chandra KrishiViswavidyalaya, Mohanpur, Nadia-741235
*Corresponding author e-mail address: riteshubkv@gmail.com

ABSTRACT
*A field experiment was carried out to find the best management practices to enhance yield and Zn loading in grain. Eight treatments viz. basal Zn application with three different doses, basal Zn at three different doses along with a foliar spray at booting and two foliar spray at maximum tillering and booting long with a Control were studied. Soil application of Zn increased the available Zn content in soil at harvest and this increase was higher where Zn was applied at higher dose or applied both in soil and through foliar spray. One soil application of Zn along with one foliar application at booting stage had the better efficiency in terms of loading of Zn in grain compared to only soil application. Soil application of Zn @ 10 kg ha^{-1} along with one foliar spray of $ZnSO_4.7H_2O$ @ 0.5% at booting stage produced highest grain (5.72 t ha^{-1}) and straw (7.57 t ha^{-1}) yield. Available Zn content in soil was significantly correlated with Zn content in root (0.79**), shoot (0.64**) and grain (0.62**). Increase in available Zn increased plant height (0.78**), number of tillers per square meter (0.83**), and test weight (0.76**) as well which ultimately resulted in higher grain and straw yield. Grain and straw yield was significantly correlated with number of tiller, plant height and test weight.*
Keywords: *Tillering, Alluvial Soil, Conventional.*

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INTRODUCTION

Zinc is one of the important micronutrients essential for plants, animals and human health. It is needed in very small amount but from the nutritional point of view, it is indispensable like any other essential nutrients. Among the micronutrients, Zn is the most researched and talked about nutrients not only in India, but in the world. Fertilization of crop with zinc (Zn) has received considerable attention in recent year due to world-wide spread of its deficiency in soil and also due to malnutrition, especially in developing countries. Zinc deficiency was found to be one major reason for child death worldwide, and was responsible for nearly 450,000 deaths in children less than 5 years of age (4). According to a report published in 2002 by WHO, Zn deficiency is considered as the fifth most important risk factor responsible for illness and death in the developing world. In human body, Zn plays an important role in maintaining the structure and function of large number of macromolecules and is also found responsible for controlling over 300 enzymatic reactions (28). (12) stated that Zinc deficiency is the highest priority among micronutrients for agriculture to address.
The Zn plays very important role in plant metabolism by influencing the activities of hydrogenase and carbonic anhydrase, stabilization of ribosomal fractions and synthesis of cytochrome (29). Plant enzymes activated by Zn are involved in carbohydrate metabolism, maintenance of the integrity of cellular membranes, protein synthesis, regulation of auxin synthesis and pollen formation (18). The regulation and maintenance of the gene expression required for the tolerance of environmental stresses in plants are Zn dependent (3). Its deficiency results in the development of abnormalities in plants which become visible as deficiency symptoms such as stunted growth, chlorosis and smaller leaves, spikelet sterility. Zn deficiency can also adversely affect the quality of harvested products; plants susceptibility to injury by high light or temperature intensity and to infection by fungal diseases (18; 3).

Cereals (rice, wheat, etc.) are the major staple food in India and South East Asia which contribute more than 70% of the total energy in the diet of young children. Rice which is highly sensitive to zinc deficiency is the main food crop grown in India. India include high rainfall/drought conditions, continuous use of traditional varieties due to non-availability of seeds of improved varieties or unawareness of the farmers about them, heavy infestation of weeds/pests, low soil fertility, imbalanced use of fertilizers and many more which altogether result in low rice production. Among these factors, low soil fertility is the most important factor which not only seriously affects the rice production but reduce the quality of the rice. (5) reported Zn deficiency as a key factor in determining the rice production in several parts of India. According to Singh (26), 48% soils in India are afflicted with Zn deficiency. In countries like India where the diet is mainly cereal based, consumption of rice grown on these low Zn soils resulting low intake of zinc in young children and population. Inadequate intake of Zn to humans leads to impairment in growth and immune functions causing to infectious diseases and the risk of mortality.

Zinc has emerged as the most widespread micronutrient deficiency in soils and crops worldwide, resulting in severe yield losses and deterioration in nutritional quality. Since cereal grains are inherently low in Zn concentrations, growing them on zinc deficient soils further decreases grain zinc concentration. Almost half of the soils in the world are deficient in available zinc (25). The available Zn content is also very low in Indian soils; however, the total and available Zn content in soil holds good relationship. Significant response to Zn fertilization has been reported in a number of field crops. The Zn availability in soil is influenced by soil and management factors. Since alteration in native soil factors is not easy, hence, Zn management practices are viable and most effective methods in correcting Zn deficiency.The use of chemical fertilizers and manures, to enhance soil fertility and crop productivity has often negatively affected the complex biogeochemical cycles [27]. On the other hand, high cost associated with the application of Zn fertilizers in order to correct Zn deficiency places considerable burden on resource poor farmers. Suitable management practices are the need of the hour to combat Zn deficiency in soil as well as to produce good quality crops. With this background, the present study was undertaken to address appropriate management of zinc fertilizer as well as time and method of zinc application in rice.

MATERIAL AND METHODS

The experiment was laid out at Central Research Farm (AICRP on Micronutrients) Gayeshpur, BCKV, Nadia (22.96^{0}N, 88.49^{0}E and 8.4m above MSL) under Gangetic Alluvial Zone of West Bengal. The soil of the experimental area was clay loam (sand (25.6 %), silt (35.4 %) and clay (39.0 %)) in texture, slightly acidic (pH 6.2), medium in oxidizable organic carbon (5.6 g kg^{-1}) and low in Zn (2.2 mg kg^{-1}) (table 1).

Rice (variety: *Swarnamasuri)* was grown conventionally in the Kharif season (June to November) with recommended dose of fertilizers, i.e. 60:30:30and applied through urea and sufala (10:26:26) along with well decomposed FYM (6 Mg ha^{-1}). Water level up to 5 cm height was maintained in the plots from transplanting to grain filling stage. Seven different treatments of Zn were laid out along with a control, in a randomized block design (RBD) with three replications (altogether 24 plots) in 3m×26m plot size each.viz. **T1**: Control (No Zn), **T2**: Soil application of Zn @ 2.5 kg ha^{-1}, **T3**: Soil application of Zn @ 5 kg ha^{-1}, **T4**: Soil application of Zn @ 10 kg ha^{-1}, **T5**: Soil application of Zn @ 2.5 kg ha^{-1} along with one foliar spray of $ZnSO_4.7H_2O$ @ 0.5% at booting stage, **T6**: Soil application of Zn @ 5 kg ha^{-1} along with one foliar spray of $ZnSO_4.7H_2O$ @ 0.5% at booting stage, **T7**: Soil application of Zn @ 10 kg ha^{-1} along with one foliar spray of $ZnSO_4.7H_2O$ @ 0.5% at booting stage, **T8**: Two foliar application of $ZnSO_4.7H_2O$ @ 0.5% at maximum tillering stage and at booting stage.

Surface soils (0-0.20m) were collected at three different stages viz. maximum tillering, panical initiation and harvesting stages from all three replications. Subsequently soil samples were air-dried, grinded and mixed thoroughly and then passed through 2mm sieve for analysis of different parameters. Collected soils were analyzed for pH water and electrical conductivity (EC) as described by Jackson et al, 1973. Oxidizable organic carbon and was determined following the acid digestion method (30). Available zinc was extracted following the DTPA extraction method (16) and analyzed in Atomic Absorption Spectrophotometer (AAS).

Table 1: Initial properties of soil

Initial soil properties	
Sand (%)	25.6
Silt (%)	35.4
Clay (%)	39.0
Textural class	Clay loam
pH	6.2
EC (dSm^{-1})	0.13
SOC ($g\ kg^{-1}$)	5.6
Available Zinc ($mg\ kg^{-1}$)	2.2

Root and shoot samples were collected at three replicates during maximum tillering, panical initiation and after harvest. Subsequently the samples were sun dried followed by oven drying, grounded and analysed for total zinc content by dry ashing method (21)along with the grain samples collected after harvest. Ashed samples were extracted with 5 ml of 2N HCl and analyzed in AAS.
Simple correlation matrix was worked out between soil properties and different forms of sulphur. Also linear regression equations have been drawn between different methods of sulphur estimation.

RESULTS AND DISCUSSION

Soil samples collected at three different stages of rice were analysed for pH. Electrical conductivity (EC) and oxidizable organic carbon (SOC) and the results were depicted in table 2. pH in soil varied from 5.9 to 6.3 at maximum tillering, 5.8 to 6.2 at panical initiation (PI) and 5.5 to 5.8 at harvesting stage. The variation in pH was non-significant among the treatments applied. Though, there was slight decrease in pH towards harvesting from maximum tillering stage. There was slight increase in EC towards harvesting from the initial value. Irrespective of treatments applied and different stages of rice growth, EC varied from 0.087 to 0.187 dSm^{-1}. With the advancement of growth stages of rice, EC was increased lightly. Also there was significant increase in EC due to the applied zinc. This increase in EC with the advancement of growth stages as well as with the Zn fertilization might be explained by the application of huge amount of fertilizer (N,P,K and Zn) along with manures that resulted in release of soluble salts and their accumulation in soil. (23) also

Table 2: Properties of soil affected by different level of applied Zn at three different stages of rice growth

	pH			EC(dSm^{-1})			SOC($g\ kg^{-1}$)		
Treatments	Max. tillering	PI	Harvesting	Max. tillering	PI	Harvesting	Max. tillering	PI	Harvesting
T1	6.3^{a}	6.2^{ab}	5.8^{a}	0.087^{e}	0.109^{f}	0.117^{g}	8.35^{b}	7.65^{d}	6.43^{d}
T2	6.2^{b}	6.2^{a}	5.8^{a}	0.097^{d}	0.117^{e}	0.120^{fg}	9.43^{a}	8.23^{c}	6.66^{c}
T3	6.2^{b}	6.0^{abc}	5.7^{ab}	0.10^{3c}	0.130^{d}	0.140^{e}	9.44^{a}	8.31^{c}	6.47^{d}
T4	6.0^{b}	6.0^{bc}	5.6^{bc}	0.109^{ab}	0.135^{c}	0.150^{d}	9.41^{a}	8.60^{b}	6.68^{c}
T5	6.1^{b}	6.0^{abc}	5.8^{a}	0.096^{d}	0.151^{b}	0.156^{c}	9.40^{a}	8.64^{b}	6.69^{c}
T6	6.2^{b}	5.9^{c}	5.7^{ab}	0.107^{bc}	0.179^{a}	0.177^{b}	9.47^{a}	8.88^{a}	7.48^{a}
T7	5.9^{c}	5.8^{c}	5.5^{c}	0.112^{a}	0.183^{a}	0.187^{a}	9.48^{a}	8.72^{ab}	7.55^{a}
T8	6.2^{b}	6.0^{abc}	5.8^{a}	0.097^{d}	0.122^{e}	0.124^{f}	9.29^{a}	7.69^{d}	7.21^{b}

T1= No Zn (Control); T2= Soil application of Zn @ 2.5 kg ha-1; T3= Soil application of Zn @ 5 kg ha-1; T4= Soil application of Zn @ 10 kg ha-1; T5= Soil application of Zn @ 2.5 kg ha-1 + one foliar spray of ZnSO4.7H2O @ 0.5% at booting stage; T6= Soil application of Zn @ 5 kg ha-1 + one foliar spray of ZnSO4.7H2O @ 0.5% at booting stage; T7= Soil application of Zn @ 10 kg ha-1 + one foliar spray of ZnSO4.7H2O @ 0.5% at booting stage; and T8= Two foliar application of ZnSO4.7H2O @ 0.5% at maximum tillering and booting stage. Values with different lower case (a–g) superscript letters are significantly different between treatments at $P < 0.05$ (Duncan multiple range tests for separation of mean).

Reported similar results on the relationship between soil solution EC and solution concentration of basic cations in flooded Asian soils. (9) also reported that there was a significant positive relation between NO_3-N values and EC values in a manure addition study. (6) observed increase in soil EC with application of chicken manure.

Table 3: Available Zn content in soil affected by different level of applied Zn at three different stages of rice growth

Treatments	Max. tillering	PI	Harvesting
	mg kg^{-1}		
T1	2.23^{d}	1.95^{f}	1.74^{f}
T2	3.30^{c}	3.46^{d}	3.68^{d}
T3	3.63^{b}	4.01^{c}	3.90^{d}
T4	3.78^{ab}	4.37^{b}	5.13^{b}
T5	3.36^{c}	4.44^{b}	4.78^{c}
T6	$3.82a^{b}$	4.87^{a}	4.88^{c}
T7	4.05^{a}	5.11^{a}	5.41^{a}
T8	3.12^{c}	3.15^{e}	3.40^{e}

Values with different lower case (a–f) superscript letters are significantly different between treatments at P <0.05 (Duncan multiple range tests for separation of mean).

Oxidizable organic carbon in soil varied from 8.35 to 9.48 at maximum tillering, 7.65 to 8.88 at panical initiation (PI) and 6.43 to 7.55 g kg^{-1}at harvesting stage (table 2). Irrespective of different growth stages of rice all the treatments showed build up in SOC content compared to control soil (no Zn application), and this build up was highest in T6 and T7. Irrespective of treatments there was decrease in SOC content in soil with advancement of rice growth. We know intensive cultivation exposes soil towards environment (temperature and microorganism) and thereby leads to oxidation of organic carbon in soil, particularly during the maturity of rice when there was no standing water. In another study in tropical Brazil showed that paddy fields loose much SOC when compared to native vegetation in the tropics]17].The rice field ecosystem is commonly characterized by flooding conditions and high percolation rate. Leaching loss of DOC from paddy soil, which is relatively rich in organic matter, is always overlooked. Soil wetting and drying cycles influence a large number of biological and chemical processes [14]. Solubility of soil organic carbon (SOC) and its leaching risks will change when the rice field is exposed to non flooding conditions under water-saving irrigation management.

Available Zn content in soil was measured by DTPA extraction method and presented in table 3& Fig. 1. Results showed that Zn content in soil increased at harvest in all the treatments except in control soil where there was no Zn applied either in soil or as foliar application. At harvest, this increase was highest(5.41 mg kg^{-1}) where Zn was applied in soil @ 10 kg ha^{-1} along with one foliar spray of $ZnSO_4.7H_2O$ @ 0.5% at booting stage (table 3).Two foliar application of $ZnSO_4.7H_2O$ @ 0.5% at maximum tillering stage and at booting stage resulted in higher Zn accumulation (3.40 mg kg^{-1}) in soil compared to control (1.74 mg kg^{-1}) but lesser than all the other treatments. From the result it was clearly seen that soil application of Zn increased the available Zn content in soil at harvest and this increase was higher where Zn was applied at higher dose or applied both in soil and through foliar spray, as higher amount of Zn was left over after the fulfillment of plant requirement. [7] also reported that the application of zinc to rice crop improved the availability of zinc in post-harvest soil.. There was a decrease in Zn concentration at harvest (1.74 mg kg^{-1})from the initial content (2.22 mg kg^{-1}) in control soil which is understandable. Due to the crop removal, concentration of available Zn has decreased from the initial content in control soil.(8) also reported higher DTPA-extractable Zn in soils fertilized with Zn compared to control. Zinc concentrations generally decreased in rice soils after flooding. The decrease in concentration with the flooding may be associated with increase in soil pH after flooding [22]. With the advancement of growth of rice redox potential of soil tends to increase which might be another reason behind the decreased Zn concentration in soil at harvest, particularly in Control-where no Zn was applied.The main cause of deficiency of planta vailable Zn in soil is the precipitation or adsorption of Zn with various soil components, depending on the pH and redox potential [14].lowland paddy fields undergo at least two flooding and draining cycles, which are known to lead to fluctuations in the redox conditions [20].

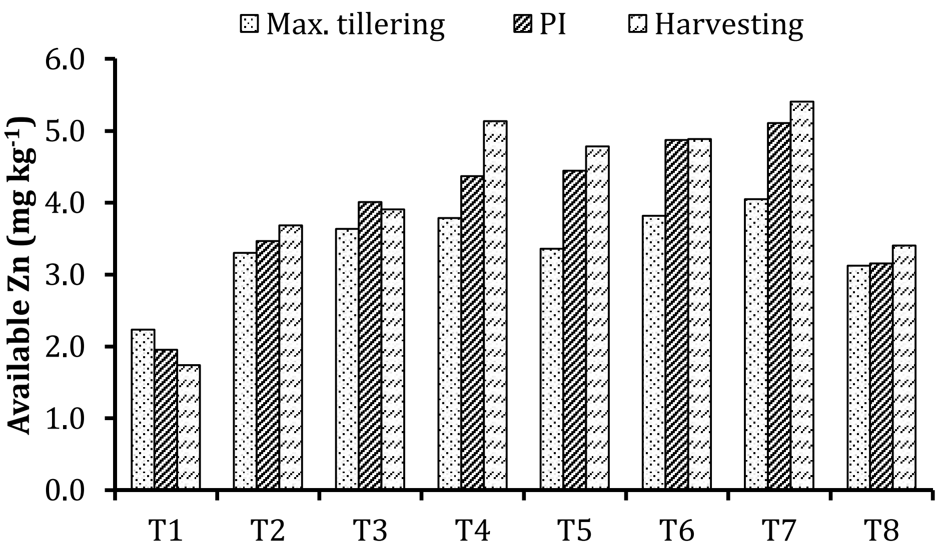

Fig. 1: Effect of different level of applied Zn on available Zn content in soil at three different stages of rice growth

Total Zn content in root, shoot at maximum tillering and panicle initiation and in root, shoot and grain at harvesting stage was analyzed by dry ashing method and the results were presented in table 4 and Fig. 2. Irrespective of treatments Zn content in root and shoot were highest at panical initiation (57.89 and 38.72 mg kg^{-1}) followed by harvesting (54.59 and 43.87 mg kg^{-1}) and maximum tillering stage (52.12 and 36.62 mg kg^{-1}). Accumulation of Zn was highest in root (54.59 mg kg^{-1}) followed by shoot (43.87mg kg^{-1}) and grain(39.02 mg kg^{-1}) irrespective of treatments. Soil application of Zn @ 2.5 kg ha^{-1}(T5),@ 5 kg ha^{-1} (T6)and @ 10 kg ha^{-1} (T7)along with one foliar spray of $ZnSO_4.7H_2O$ @ 0.5% at booting stage resulted in 41.88, 43.25 and 42.92 mg kg^{-1} Zn respectively in grain that are significantly higher than any other treatments. Zn concentration in grain was higher (39.9 mg kg^{-1}) where there was two foliar application of $ZnSO_4.7H_2O$ @ 0.5% at maximum tillering stage and at booting stage (T8)compared to treatments where only soil application (T2, T3 and T4) was performed. From the results we can conclude that one soil application of Zn along with one foliar application at booting stage has the better efficiency in terms of loading of Zn in grain compared to only soil application. [2] and Yuan *et al.,* [32] also come up with similar kind of results that amongst different methods, the foliar spray of zinc is an efficient one for enhancement of zinc content in rice grains.

Table 4: Effect of different level of applied Zn on total Zn content in root and shoot at maximum tillering and panical initiation and in root, shoot and grain at harvesting stage of rice growth

Treatments	Max. tillering		PI		Harvesting		
	Root	Shoot	Root	Shoot	Root	Shoot	Grain
	mg kg^{-1}						
T1	44.86c	32.11^{d}	50.25^{d}	34.02^{e}	49.73^{d}	40.64^{d}	35.15^{c}
T2	51.89^{ab}	33.09^{cd}	51.08^{d}	34.89^{de}	52.39^{c}	40.61^{d}	36.35^{c}
T3	52.68^{ab}	33.27^{cd}	56.30^{c}	36.40^{c}	56.70^{ab}	41.38^{d}	35.86^{c}
T4	53.67^{ab}	38.33^{ab}	55.82^{c}	39.26^{b}	57.13^{a}	42.36^{d}	36.88^{c}
T5	53.33^{ab}	40.73^{a}	60.21^{b}	42.47^{a}	54.23^{bc}	45.77^{b}	41.88^{a}
T6	54.37^{ab}	39.95^{ab}	64.99^{a}	41.57^{a}	56.43^{ab}	47.80^{a}	43.25^{a}
T7	54.82^{a}	38.95^{ab}	63.09^{ab}	42.36^{a}	57.53^{a}	48.30^{a}	42.92^{a}
T8	51.38^{b}	36.53^{bc}	61.3^{4b}	38.77^{b}	52.57^{c}	44.06^{c}	39.90^{b}

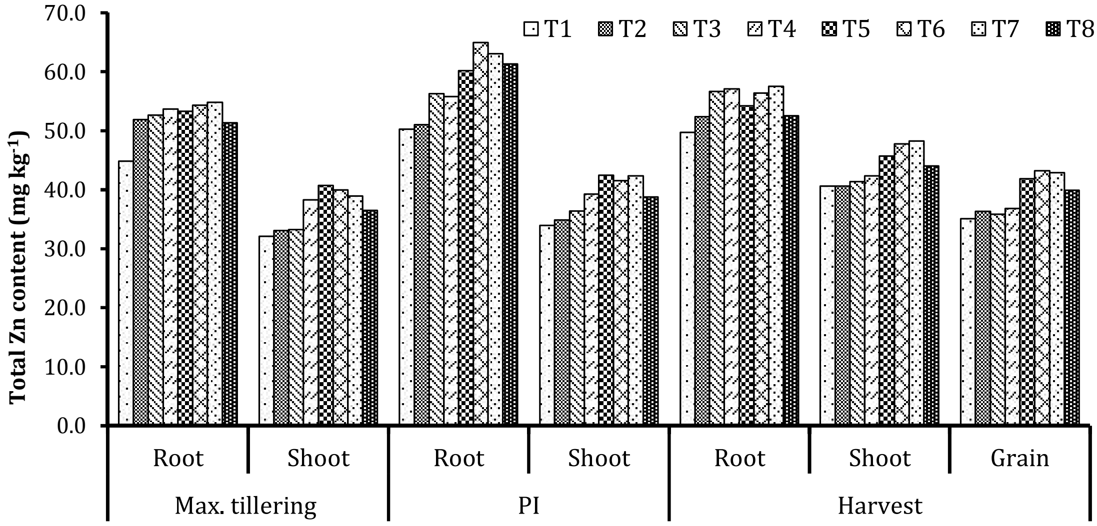

Fig 2: Effect of different level of applied Zn on total Zn content in root and shoot at maximum tillering and panical initiation and in root, shoot and grain at harvesting stage of rice growth

Effect of applied Zn on growth parameters, uptake of Zn, grain and straw yield of rice was presented on table 5. Application of Zn in soil along with one foliar spray (T5, T6 and T7) significantly increased the plant height, number of tiller per m^2 and test weight as well compared to control (Table 5). Though with in them (T5, T6 and T7) there was no significant difference. The increase in plant height and number of tillers per m^2 by soil application of Zn may be attributed due to increase in available Zn in soil compared to Control. Similar results were reported (10;11).Zn application might have increased IAA synthesis leading to increase in plant height via increase in inter node length as well as number of panicle. These results are in agreement with [19].

Table 5: Effect of different level of applied Zn on uptake of Zn, yield and other yield attributes in rice.

Treatments	Plant height			Number of tiller m^{-2}	Test weight	Grain yield	Straw yield	Harvest index	Uptake of Zn
	Max. tillering	PI	Harvesting						
	(cm)				(g)	(t ha^{-1})			kg ha^{-1}
T1	33.5^{c}	89.1^{e}	96.9^{d}	373^{c}	20.5^{c}	4.63^{e}	6.41^{b}	0.421^{a}	0.163^{d}
T2	37.8a	92.9^{d}	100.7^{c}	392^{b}	21.1^{bc}	4.99^{c}	6.72^{ab}	0.426^{a}	0.181^{cd}
T3	37.6ab	100.1^{c}	102.1^{c}	413^{a}	21.2^{bc}	5.10^{bc}	6.87^{ab}	0.427^{a}	0.187^{c}
T4	39.1a	101.7^{ab}c	103.6^{bc}	418^{a}	21.5^{b}	5.12^{bc}	7.02^{ab}	0.422^{a}	0.189^{c}
T5	39.6a	100.8^{bc}	106.0^{ab}	421^{a}	22.4^{a}	5.44^{ab}	7.28^{a}	0.428^{a}	0.228^{b}
T6	39.9a	104.1^{ab}	107.3^{a}	416^{a}	23.0^{a}	5.45^{ab}	7.45^{a}	0.422^{a}	0.236^{ab}
T7	38.8a	105.1^{a}	109.0^{a}	421^{a}	23.0^{a}	5.72^{a}	7.57^{a}	0.431^{a}	0.246^{a}
T8	35.0bc	92.0d^{e}	94.4^{d}	388bc	21.0b^{c}	4.79^{de}	7.06^{ab}	0.404^{a}	0.191^{c}

Soil application of Zn @ 10 kg ha^{-1} along with one foliar spray of $ZnSO_4.7H_2O$ @ 0.5% at booting stage (T7) produced highest grain (5.72 t ha^{-1}) and straw (7.57 t ha^{-1}) yield. Soil + Foliar application of Zn significantly increased test weight in rice compared to only soil application of Zn and Control. Increased test weight of rice cultivars upon Zn fertilization might be due to the increase in carbonic an hydrase activity and more carbohydrate accumulation in the seeds (2).Soil application of Zn along with one foliar spray (T5, T6 and T7) produced higher grain and straw yield compared to only soil application (T2, T3 and T4) or only foliar spray (T8) and Control (T1) (Table 5). Uptake of Zn was higher where Zn was applied in soil as well as foliar spray. The application of zinc as basal plus foliar spray was found to have positive and significant influence on grain yield and Zn uptake [16]. Soil application of Zn helps in increasing number of tillers, plant height and overall growth of rice plant initially which ultimately reflected in higher yield and Zn uptake particularly in Zn deficient soils. Also the Zn sprayed by foliar fertilizers is absorbed by the leaf epidermis, and remobilized and transferred into the rice grain through the phloem [32] with the contribution of several Zn-regulating transporter proteins [9].

Table 6: Pearson correlation table between different properties of soil.

	pH	Avl. Zn	SOC
Avl. Zn	-.550**		
SOC	-0.264	.522**	
EC	-.575**	.832**	.691**

** Correlation is significant at the 0.01 level (2-tailed).

Available Zn content in soil was correlated with the properties of soil and the results were presented on table 6. It was seen that available Zn content in soil was significantly negatively correlated with soil pH (-0.55**) but positively correlated with oxidizable organic carbon (0.69**) and electrical conductivity (0.83**). Zinc accessibility is profoundly reliant on pH. At the point when the pH is over 6, the accessibility of Zn is normally exceptionally low. The accessibility of Zn in antacid soils is decreased because of lower dissolvability of the dirt Zn (1).Soil zinc found in soil solution, as the free ion Zn^{2+} associated with organic and inorganic ligands, on exchanged sites of soil, bound by organic matter and occluded in oxides and hydroxides of Al and Fe (13).With the increase in pH zinc form insoluble complexes like $ZnCO_3$, $Zn(OH)_2$, ZnS, etc. and thereby reduces its availability in soil. Whereas organic matter act as chelating agent, forms stable complexes with Zn and reduces its loss through various means [29]. Also mineralization of organic matter releases a small amount of Zn^{2+} in soil.

Table 7: Multiple correlations between Available Zn in soil at harvest, Zn in root, shoot, grain, yield and other yield attributes.

	Available Zn	Zn in root	Zn in shoot	Zn in grain	Plant height	No. of Tiller	Test weight	Grain yield	Straw yield
Zn in root	.799**								
Zn in shoot	.648**	.513*							
Zn in grain	.626**	.441*	.900**						
Plant height	.786**	.660**	.641**	.555**					
No. of Tiller	.838**	.788**	.524**	.534**	.764**				
Test weight	.764**	.502*	.814**	.814**	.783**	.606**			
Grain yield	.794**	.695**	.724**	.726**	.805**	.744**	.826**		
Straw yield	.619**	.499*	.676**	.615**	.443*	0.39	.555**	.513*	
HI	.166	.205	.043	.136	.371	.393	.243	.474*	-.498*

** Correlation is significant at the 0.01 level (2-tailed). * Correlation is significant at the 0.05 level (2-tailed).

Pearson correlation was performed between available Zn in soil at harvest, total Zn in root, shoot and grain, physiological parameters like plant height, number of tiller, test weight, grain and straw yield. Results were depicted on table 7. Available Zn content in soil was significantly correlated with Zn content in root (0.79**), shoot (0.64**) and grain (0.62**). Increase in available Zn increased plant height (0.78**), number of tillers per square meter (0.83**), and test weight (0.76**)as well which ultimately resulted in higher grain and straw yield. Grain and straw yield was significantly correlated with number of tiller, plant height and test weight (table 7).

CONCLUSION

Data from these field study show that application of Zn in rice is mandatory to produce at maximum potential particularly in Zn deficient soils in India. Among different management practices studied soil application of Zn along with a foliar spray at booting stage of rice (T5, T6 and T7) was most useful in enhancing the quality (grain Zn content) as well as yield. Though, the rate of Zn application in soil should be based on its initial Zn content. In our case application of Zn @ 10 kg ha^{-1} (T7) produced maximum yield as well as Zn content in grain compared to Zn @ 5 kg ha^{-1} (T6) and @ 2.5 kg ha^{-1}(T5) as, our soil was low in initial Zn content. Foliar spray of zinc sulfate is an effective and relatively economical method only in moderately zinc-deficient soil, but soils with higher requirements might have some limitations for foliar spray.

CONFLICT OF INTEREST

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

REFERENCES

1. Adhikary, S., Bihari, B., Kundu, R., Dutta, J. and Mukherjee, A. K. (2019).Essentiality with Factor Influencing Accessibility of Zinc in Crops and Human.*Int.J.Curr.Microbiol. App.Sci.* 8(11): 2158-2170.
2. Bandara, W.M.J. and Silva, L.C. (2000).Rice crop response to zinc application in low humicgley soils of low country intermediate zone.*Journal of Soil Science Society Sri Lanka*, 12: 40-50.
3. Cakmak I (2009). Enrichment of fertilizers with zinc: an excellent investment for humanityand crop production in India. J Trace Elem Med Biol.;23(4):281–289.
4. Cakmak, I. (2000). Role of zinc in protecting plant cells from reactive oxygen species. *New Phytol*.146:185–205.
5. Chaudhary, S.K., Thakur, S.K. and Pandey, A.K. (2007).Response of wetland rice to nitrogen and zinc.*Oryza.* 44 (1): 31-34.
6. Dikinya, O., and Mufwanzala, N. (2010). Chicken manure enhanced soil fertility and productivity: Effects of application rates. *Journal of Soil Science and Environmental Management*, 1, 46–54.
7. Duraisamy, P., Kothandaramam, G.V.,and Chellamuthu, S. (1988) Effect of amendments and zinc on the availability, content and uptake of zinc and iron by rice Bhavani in sodic soil. *Madras Agric J.* 75:119–124
8. Dwivedi, R, and Srivastva, P.C. (2014).Effect of zinc sulphate application and the cyclic incorporation of cereal straw on yields, the tissue concentration and uptake of Zn by crops and availability of Zn in soil under rice-wheat rotation.*Int J Recycl Org Waste Agric*, 3: 53.
9. Eigenberg, R.A., Doran, J.W., Niennaber, J.A., Ferguson, R.B.,and Woodbury, B.L. (2002). Electrical conductivity monitoring of soil condition and available N with animal manure and a cover crop. *Agr.Ecosys.andEnvir.* 88:183-193.
10. Ghoneim, A.M, Ueno H, Asagi N and Watanabe T. (2012), Indirect ^{15}N Isotope techniques for estimating N Dynamics and N Uptake by rice from poultry manure and sewage sludge. Asian Journal of Earth Sciences.; 5(2):63–69.
11. Ghoneim, A.M. (2014) Nitrogen and carbon uptake by some rice cultivars from15NH4Cl and ^{13}C-U-glucose labeling fertilizer. International Journal of Agronomy and Agricultural Research.;4(4):20–27.
12. Graham, R.D. (2008). Micronutrient deficiencies in crops and their global significance.In:B. J. Alloway (ed). Micronutrient deficiencies in global crop production.*Springer*, New York, 41–61.
13. Havlin, J. L., Beaton, J. D., Tisdale, S. L. and Nelson, W. L. (2005. Soil fertility and fertilize – an introduction to soil nutrient management . Pearson Education Inc.
14. Impa, S.M.,and Johnson-Beebout S.E. 2012. Mitigating zinc deficiency and achieving high grain Zn in rice through integration of soil chemistry and plant physiology research. *Plant and Soil* 361, 3–41.
15. Kulhare, P.S., Tagore, G.S., and Sharma, G.D. (2016).Effect of zinc fertilization on yield and zinc uptake efficiency of rice genotypes grown in central India.*International Journal of Agriculture Sciences*, 8(2): 964-967.
16. Li, S., Zhou, X., Huang, Y., Zhu, L., Zhang, S., Zhao, Y., Guo, J., Chen, J., and Chen, R. (2013).Identification and characterization of the zinc-regulated transporters, iron-regulated transporter-like protein (ZIP) gene family in maize.*BMC Plant Biology*. 8(13): 114- 125.
17. Marrenjo, G. J., Pádua, E. J. D., Silva, C. A., Soares, P. C. and Zinn, Y. L.(2016) .Impacts of long-term cultivation of fooded rice in gley sols. PesquisaAgropecuáriaBrasileira. 51, 967–977 (in Portuguese with English abstract).
18. Marschner, H. (1995). Mineral nutrition of higher plants (2nded.). London: AcademicPress.
19. Movahhedy-Dehnavy, M., Modarres-Sanavy, S.A.M., Mokhtassi-Bidgoli A.(2009). Foliar application of zinc and manganese improves seed yield and quality of safflower (Carthamustinctorius L.) grown under water deficit stress. *Industrial Crops and Products*.; 30(1):82-92.
20. Pan, Y.Y., Bonten, L.T.C., Koopmans, G.F., Song, J., Luo, Y.M., Temminghoff, E.J.M., et al. (2016). Solubility of trace metals in two contaminated paddy soils exposed to alternating flooding and drainage. *Geodema*, 261, 59–69. doi:10.1016/j.geoderma.2015.07.011.
21. Piper, C. S. (1944) Soil and Plant Analysis, Interscience, New York.
22. Ponnamperuma, F.N. (1975). "Micronutrient limitations in acid tropical rice soils". In Soil management in Tropical America, Edited by: Bornemisza, E. and Alvarado, A. 330–347. Raleigh: North Carolina State University.
23. Ponnamperuma, F.N., (1965).Dynamic aspects of flooded soils and the nutrition of the rice plant. In The Mineral Nutrition of the Rice Plant, Johns Hopkins Press, Maryland, , pp. 295–328.
24. Shuman, L.M. (1998). Micronutrient fertilizers. In: Z. Rengel (ed.) Nutrient Use in Crop Production. The Haworth Press, New York, USA, pp: 165-195.
25. Sillanpaa, M. (1982).Micronutrients and the Nutrient Status of Soils – A Global Study.FAOSoils Bulletin 48, FAO, Rome.
26. Singh, M.V. (2009). Evaluation of current micronutrient stocks in different Agro ecological zones of India for sustainable crop production. Fert.News. 46: 25-42.
27. Sperotto, R.A., Ricachenevsky, K.F., Waldow V.A. and Janette, P.F. (2012).Iron biofortification in rice: It's a long way to the top. *Plant Science*, 190: 24-39.
28. Tapiero, H, and Tew K.D. (2003).Trace elements in human physiology and pathology: zinc and metallothioneins. *Biomed Pharmacother*. 57:399–411. doi: 10.1016/S0753-3322(03)00081-7.
29. Tisdale, S.L., Nelson, W.L. and Beaten, J.D. (1984). Zinc In soil Fertility and Fertilizers.*Fourthedition,Macmillan Publishing Company*, New York.382-391.
30. World Health Organization (WHO). 2002. The World Health Report.

31. Wu, C., Lu, L., Yang, X., Feng, Y., Wei, Y., Hao, H., Stoffella, P.J., and He, Z. (2010). Uptake, translocation, and remobilization of zinc absorbed at different growth stages by rice genotypes of different Zn densities. *Journal of Agriculture and Food Chemistry*. 58: 6767–6773.
32. Xiang, S.R., Doyle, A., Holden, P. A., and Schimel,J.P.(2008).Drying and rewetting effects on C and N mineralization and microbial activity in surface and subsurface California grassland soils,*Soil Biology and Biochemistry*, vol. 40, no. 9, pp. 2281–2289.