

CRITICAL LIMITS OF ZINC IN SOIL AND RICE PLANT GROWN IN ALLUVIAL SOILS OF WEST BENGAL, INDIA

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ABSTRACT

A study was conducted in 22 alluvial soils of West Bengal, India to estimate the critical limit of Zn in soil and rice plant for predicting the response of rice (*Oryza sativa*) to zinc application. The DTPA-extractable Zn was positively and significantly correlated with CEC, organic carbon and clay contents and negatively correlated with pH, silt and sand contents of soil. The DTPA-extractable Zn also showed a positive correlation with dry matter yield and plant Zn content. The critical concentration of Zn in these soils was established at 0.75 mg kg⁻¹ for rice and that of 28.0 mg kg⁻¹ in the plant tissue. Soil containing Zn below the critical limit responded appreciably to Zn fertilization. A negative response to Zn application was also observed at its higher level. The average dry matter yield increases with increasing level of Zn application up to 2.5 mg kg⁻¹ in Zn deficient soils. The average response to Zn application in rice in Zn deficient soils was found to be 68.5% and 19.9% in Zn adequate soils.

Key words: Zinc, bray's percent yield, critical limits, alluvial soil, physico-chemical properties of soil, rice.

INTRODUCTION

Rice is one of the most important food crops and a primary food source for more than one third of world's population (Prasad *et al.*, 2010). In Asia, India has the largest area under rice cultivation (44.3 million ha) accounting for 29.4 per cent of the global rice area. The productivity level in India is low (2.04 t ha⁻¹) as compared to Japan (6.25t ha⁻¹), China (6.24t ha⁻¹) and Indonesia (4.25t ha⁻¹). In India, West Bengal is one of the leading states for rice cultivation. Productivity of rice depends upon balance application of nutrients. The soils of West Bengal are poor in micronutrients

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due to continuous growing of high yielding varieties and only incorporation of macronutrients in cropping system. The deficiencies of micronutrients are of critical importance for sustaining high productivity of rice in India. Zinc is one of the essential plant micronutrients and its importance for crop productivity is similar to that of major nutrients (Rattan *et al.*, 2009). Zinc plays an important role in different plant metabolism processes like development of cell wall, respiration, photosynthesis, chlorophyll formation, enzyme activity and other bio-chemical functions (Das, 2003 and Singh, 1984).

Widespread and extensive Zn deficiency has been reported in the soils of lowland rice cultivation of India, Bangladesh, Pakistan, Philippines, Myanmar, Indonesia, Japan, Korea, Taiwan and Thailand (IRRI, 1978). In West Bengal, 55% of the soils are found to be deficient in Zn (Takkar *et al.*, 1989). Studies on Zn fertilizer proved that the application of Zn greatly influences growth, yield and quality of rice (Patnaik *et al.*, 2011 and Rahman *et al.*, 2007). The symptoms of Zn deficiency have been recorded on rice and other field crops including vegetables crops grown in soils of alluvial zone of West Bengal. Realising the importance of Zn in plant growth and at the same time seriousness of its deficiency in soils and plants, an attempt was, therefore, made to study the critical concentration of Zn in soils and rice crop which is widely grown in the region of West Bengal for making Zn application more rational.

MATERIALS AND METHODS

Twenty two soil samples in bulk from plough layer (0-20 cm) were collected from different locations of alluvial zone of West Bengal. This zone comprised of four districts viz, Nadia, Burdwan, Murshidabad, and Hoogly of West Bengal, India (Table 1), lying between $22^{\circ} 34'$ to $23^{\circ} 24'$ N latitude and $88^{\circ} 24'$ to $88^{\circ} 33'$ Longitude. These soils belong to order Inceptisols, Entisols and Alfisols (Soil Survey Staff, 2006). The collected soil samples were separately air dried ground and passed through 2 mm size sieve for laboratory analysis. Particle size distribution was done by the standard Bouyoucos hydrometer method (Gee and Bauder, 1986). Soil pH was determined by glass electrode with calomel as standard (Jackson 1973). Organic carbon was estimated by wet digestion method of Walkley and Black (Jackson, 1973). The cation exchange capacity was determined by leaching the soil with 1 N NH_4^+OAC and subsequently displacing the adsorbed NH_4^+ methods (Gupta, 2007). Available zinc content of the soil samples was extracted with DTPA-TEA (pH 7.3) extractant following the method of Lindsay and Norvell (1978) and the concentration of Zn in the extracted solution was estimated with the help of Atomic Absorption Spectrophotometer (AAS).

A pot culture experiment was conducted in a greenhouse in polythene lined pots at the Instructional farm ($22^{\circ} 57'$ N Latitude and $88^{\circ} 20'$ E Longitude), Mohanpur, West Bengal. The polythene lining was rinsed in 0.1N HCl followed by deionized water. Four kg of each soil was transferred into each pot. Recommended doses of

nitrogen, phosphorus and potassium @ 50, 11 and 21 mg kg⁻¹ N, P and K, respectively were applied as reagent grade i.e. Urea, KH₂PO₄ and KCl. Three 21 day old rice seedlings (var. IR 36) were transplanted in each pot. Zinc was applied @ 0, 1.25, 2.5 and 5.0 mg kg⁻¹ soil as reagent grade of Zinc sulphate (ZnSO₄, 7H₂O) after 7 days of transplanting of rice seedling. Each treatment was replicated thrice in completely randomized design. Watering with deionized water and intercultural operations like weed control and plant protection measures were adopted uniformly in each pot as and when required. Rice plants of above ground portion were harvested after 30 days of transplanting and washed in acidified solution, rinsed with deionized water, dried at 65 °C in a hot air oven and dry-matter yield was recorded. The dried rice plant and dried 3rd leaf samples of each pot were separately powdered in a warring stainless steel grinder. The dry powdered plant samples were digested in a mixture of 10:4:1 of HNO₃: HClO₄: H₂SO₄ on a hot plate and filtered through Whatman No.42 for estimation of Zn with the help of Atomic Absorption Spectrophotometer (AAS). The critical value of DTPA-extracted zinc in soil and in plant were determined by plotting the Bray's percent yield against soil DTPA-extracted zinc content and separately against plant tissue zinc content respectively, following the method of Cate and Nelson (1965).

$$\text{Bray's percent Yield} = \frac{\text{Yield without Zn treatment}}{\text{Yield at optimum Zn tretment}} \times 100$$

Simple correlation analysis was carried out to establish the relationships between the Zn and soil properties.

RESULTS AND DISCUSSION

Soils properties

The data of DTPA-extracted zinc and relevant physical and chemical properties of the soils of alluvial zone of West Bengal are presented in table 1. From data it was seen that soil texture varied from sandy to clay. The soils had pH values ranging from 5.6 to 7.5 with a mean value of 6.5. Soils were slightly acidic to neutral in reactions. The organic carbon status of soil samples ranged from 4.5 to 9.5 g kg⁻¹ with a mean value of 6.5 g kg⁻¹. In general, soils were low in organic carbon content and more than 60 per cent soils were found to be low in organic carbon. The range of values of cation exchange capacity was 6.5 to 32 cmol (p+) kg⁻¹ with a mean value of 15.81 cmol (p+) kg⁻¹. The results are in agreement with earlier works of Debnath *et al.*, (2009) and Thakur *et al.*, (2011).

Critical limits of zinc in soils and third leaf rice plant

The available Zn content ranged from 0.60 to 0.97 mg kg⁻¹ with a mean value of 0.79 mg kg⁻¹ (Table 1). The percent of dry matter yield of rice ranged between 53.2- 104.9 with a mean value of 74.9. The value of Zn concentration in 3rd leaf of

rice crop, total Zn in entire shoot and Zn uptake by rice shoot in no Zn applied pots were 15.1-39 mg kg⁻¹, 20- 45 mg kg⁻¹ and 108- 661.5 µg pot⁻¹ with respective mean value of 24.5 mg kg⁻¹, 32.1 mg kg⁻¹ and 329.2 µg pot⁻¹ (Table 2). The plot of Bray's per cent yield against soil available Zn and plant tissue Zn revealed 0.75 and 28.0 mg kg⁻¹, respectively as the critical concentration of Zn in soils and plant (Figure 1 & 2). These values are close to critical level of Zn (0.83 mg kg⁻¹) as observed by Rahman *et al.*, (2007), Muthukumararaja *et al.*, (2012) and Gangwar and Chandra (1975). However, critical limit of DTPA-extracted Zn and plant tissue Zn was 0.76 mg kg⁻¹ soil and 21.5 mg kg⁻¹ reported by Sakal *et al.*, (1984) for rice in Sub-Himalayan hill and forest soils of India, below which appreciable responses to Zn application were observed. Based on the soil test, plant analysis and response of different crops to the application of Zn in greenhouse and field trial, the critical limit of Zn of 0.60 g kg⁻¹ (DTPA-extracted) for rice and wheat has so far been fixed for West Bengal (Das and Saha, 1999).

Effect of zinc on dry matter yield

The data presented in table 3 revealed that the average response in dry matter yield (%) at optimum level of applied Zn in soils below critical limit ranged from 51.2 to 89.6 per cent with mean value of 68.5 per cent. With increasing the level of Zn content in soil above the critical limit, the percentage responses also decreased which varied from (-) 5.2 to 70.3 per cent with a mean value of 19.9 per cent. On the other hand, the application of Zn increased the average shoot yield from 8.4 to 11.76 g pot⁻¹ up to 5.0 mg Zn kg⁻¹ soil below the critical value (Patnaik and Bhupal, 2001). The positive effect of Zn might be due to its beneficial effect on metabolism (Rashid and Fox 1992). Whereas, above the critical value, the application of Zn fertilizer increased the average shoot yield marginally from 11.38 to 13.04 g pot⁻¹ up to 2.5 mg Zn kg⁻¹ soil. However, a substantial amount of average dry matter yield decreased with increasing levels of applied zinc fertilizer in the soils containing Zn above critical limit up to 5.0 mg Zn kg⁻¹ soil. The decrease in dry matter yield at higher Zn levels may be ascribed to Zn toxicity in plant tissue (Singh, 1984). Based on critical value of available Zn, soils were grouped into deficient and adequate classes (Table 3). Considering critical value of Zn in soils (0.75 mg kg⁻¹), 13 soils were rated to be adequate and 53.8% soils belonging to this category responding to Zn application. Whereas, 100% soils below the critical value showed the positive response to Zn application and number of soils in this category were nine (9). However, closer examination indicated that the magnitude of mean percentage response due to 2.5 mg kg⁻¹ level of Zn application over 0 mg kg⁻¹ was found to be maximum (Table 2). This indicated that Zn can be applied for rice @2.5 mg kg⁻¹ in the soils of alluvial zone of West Bengal, where the Zn content was below 0.75 mg kg⁻¹. Naik and Das (2010) reported that the application of zinc as Zn-EDTA @ 1 kg ha⁻¹ to low land rice soil of West Bengal resulted the 37.8% and 20.9 % greatest increase in grain and straw yield of rice respectively, over the control.

Correlation among soil properties and zinc

The DTPA- extracted Zn exhibit significant positive correlation with organic carbon ($r = 0.63^{**}$), Clay ($r = 0.62^{**}$), CEC ($r = 0.71^{**}$), and Bray's percentage yield ($r = 0.77^*$) of the soils (Table 4), whereas, a negative relationship was also observed between pH ($r = -0.11$), silt ($r = -0.47^*$) and sand ($r = -0.04$). Such behaviour was also reported by Yadav and Meena (2009) and Thakur *et al.*, (2011). This suggests that organic matter, clay and CEC are the major factors of determining the Zn availability in soils. Further, Bray's percentage yield have significant and positive association with Zn concentration in plant tissues of 3rd leaf and ($r = 0.97^{**}$) and total Zn concentration in plant tissues ($r = 0.97^{**}$). Similar correlation was also reported by Rahman *et al.*, (2007).

CONCLUSION

The results indicate that the critical limit values of DTPA-extracted Zn in soil and third leaf of the rice plants were 0.75 and 28.0 mg kg⁻¹, respectively. It is evident from the study that Zn @ 2.5 mg kg⁻¹ needs to be applied to obtain optimum yield for rice in the soils of alluvial zone of West Bengal. The soils will likely respond to Zn application more when it contains less than 0.75 mg kg⁻¹ DTPA- extracted Zn.

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Table 1. Soil properties and DTPA-extractable zinc in experimental soils.

Locations/Districts		Physico-chemical properties of soils							DTPA-extractable zinc (mg kg ⁻¹)	Soil Order
		pH	Organic carbon (g kg ⁻¹)	Sand	Silt	Clay	Textural Classes	CEC C mol (p+)kg ⁻¹		
Nadia										
1	Kaligunj	6	4.5	18.7	68	13.3	sil	6.5	0.60	Alfisols
2	Debogram	7.3	6.7	30.8	46	23.2	l	8.6	0.68	Inceptisols
3	Nakashipara	6.8	5.0	24.2	54.6	21.2	sil	8.5	0.63	Entisols
4	Dhubulia	7.1	4.7	19	62	19	sil	8.5	0.60	Inceptisols
5	Ranaghat	6.7	6.2	14.2	50.8	35	sicl	19.2	0.86	Inceptisols
6	Chakdah	7	8.9	12	42.4	45.6	sic	20.9	0.92	Entisols
Burdwan										
7	Konarpara	5.8	6.7	25.8	44.2	30	l	12.5	0.70	Alfisols
8	Balidanga	6.2	5.0	48.4	26	25.6	l	12.2	0.73	Entisols
9	Srirampur	6.5	5.5	29.2	30	40.8	c	16.4	0.70	Inceptisols
10	Mirzaqpur	6.5	8.3	30.2	35	34.8	cl	18	0.96	Inceptisols
11	Hangram	6.2	7.2	25.4	44.6	30	cl	16.4	0.82	Inceptisols
12	Totpara	5.6	7.6	43.4	20	36.6	c	18.4	0.94	Alfisols
13	Banpara	6.1	6.6	35.6	42.1	22.3	l	14.8	0.86	Inceptisols
14	Ghoghat	6	4.7	47	25	28	sc	18.1	0.74	Entisols
15	Shyam sundarpur	6.2	7.8	30	35.1	34.9	cl	14.1	0.95	Entisols
Murshidabad										
16	Sagardihi	6.2	5.3	22	37.1	40.9	c	19.9	0.82	Alfisols
17	Nabagram	6.6	5.5	10	41	49	c	32	0.94	Entisols
18	Surjyapur	7.2	9.0	30.6	50.8	18.6	sil	12.6	0.80	Inceptisols
19	Gura	7.5	9.5	12	46.3	41.7	sic	20	0.97	Inceptisols
Hooghly										
20	Tarakeshwar	6.5	7.6	10.9	48.3	40.8	sic	18.2	0.78	Inceptisols
21	Balagarh	6.7	5.4	21.4	47	31.6	l	16.4	0.83	Entisols
22	Kanagar	6.7	6.8	12.3	52.1	35.6	c	15.6	0.65	Entisols
Range value		5.6-7.5	4.5-9.5	10-48.4	20-68	13.2-49		6.5-32	0.60-0.97	
Mean		6.5	6.5	25	43	32		15.81	0.79	

cl= clay loam, l=Loam, sil=silt loam, sicl=silty clay loam, sic=silty clay, c=clay, sc=sandy clay

Table 2. Effect of Zn application on dry-matter yield, Zn concentration in leaf and shoots and Zn uptake by rice.

Sl No	Shoot weight (g pot ⁻¹)				Percent dry matter yield at optimum Zn level	Total Zn in the 3 rd leaves of rice plants at no Zn pots (mg kg ⁻¹)	Total Zn in rice shoots at no Zn pots (mg kg ⁻¹)	Zn uptake by rice shoots (µg pot ⁻¹) in no Zn pots
	Application of Zn (mg kg ⁻¹ soil)							
	0	1.25	2.50	5				
1	6.1	8.2	9.5	10.6	57.6	15.8	22.0	134.2
2	6.9	8.9	10.5	11.8	57.8	17.5	26.0	179.4
3	5.8	8.0	9.7	11.0	53.2	16.3	24.0	139.2
4	6.5	8.4	9.7	11.3	58.2	16.0	24.0	156
5	12.4	13.5	13.0	12.2	91.8	33.0	40.0	496
6	8.9	11.5	12.7	12.4	70.2	21.0	29.0	258
7	7.2	9.0	10.9	11.7	61.4	16.5	26.0	187.2
8	7.5	10.1	11.7	12.4	60.5	20.0	28.0	210
9	7.9	9.5	11.5	12.0	66.2	20.5	26.0	205.4
10	14.7	14.5	13.8	13.0	102	39.0	45.0	661.5
11	12.4	13.2	14.5	13.4	85.5	28.5	37.0	458.8
12	13.5	12.8	12.7	12.2	104.9	37.0	43.0	580.5
13	11.9	12.7	12.6	12.3	94	37.0	43.0	511.7
14	8.2	10.5	12.2	12.4	65.4	19.5	27.5	225.5
15	13.8	13.6	13.4	12.4	101.9	38.0	45.0	621
16	11.5	13.1	14.2	13.1	81.6	25.6	35.0	402.5
17	12.6	13.7	13.5	13.0	92	35.0	42.0	529.2
18	10.5	12.4	13.0	12.2	80.6	23.0	33.0	346.5
19	5.4	7.1	8.8	9.2	58.8	15.5	20.0	108
20	9.5	11.7	13.2	12.3	72.5	22.0	32.0	304
21	10.9	13.0	14.2	12.0	76.5	23.5	33.0	359.7
22	6.4	8.5	10.1	11.4	55.5	18.0	26.0	166.4
Range value	5.4-14.7	7.1-14.5	8.8-14.5	9.2-13.4	53.2-104.9	15.1-39	20-45	108-661.5
Mean	9.5	11.1	12.1	12.0	74.9	24.5	32.1	329.2

Table 3. Response of rice crop to Zn application.

DTPA-extractable Zn (mg kg ⁻¹)	No. of soils	Percentage of responding soils	Average dry matter yield (g pot ⁻¹)				Average response in dry matter yield (%) at optimum level of applied Zn	
			Level of applied Zn (mg kg ⁻¹)				Range	Mean
			0	1.25	2.5	5.0		
<0.82(Deficient)	9	100	8.4	9.96	11.1	11.76	51.2-89.6	68.5
>0.82(Adequate)	13	53.8	11.38	12.52	13.04	12.28	(-)5.2-70.3	19.9

A soil was classified as responsive to Zn where the per cent response was more than 10.

Table 4. Correlation coefficient (r-values) between DTPA-extractable Zn and soil properties

Sl. no.	Variables	r- value
1	Soil pH vs DTPA-extractable Zn	-0.11
2	Organic carbon vs DTPA-extractable Zn	0.63**
3	Clay vs DTPA-extractable Zn	0.62**
4	Silt vs DTPA-extractable Zn	-0.47*
5	Sand vs DTPA-extractable Zn	-0.04
6	CEC vs DTPA-extractable Zn	0.71**
7	Bray's percentage yield vs DTPA-extractable Zn	0.77**
8	Zn concentration in 3 rd leaves vs DTPA-extractable Zn	0.69**
9	Bray's percent yield and Zn concentration in plant tissues of 3 rd leaves	0.97**
10	Bray's percent yield and total Zn concentration in plant tissues	0.97**

** ←1% level of significant, * ←5% level of significant

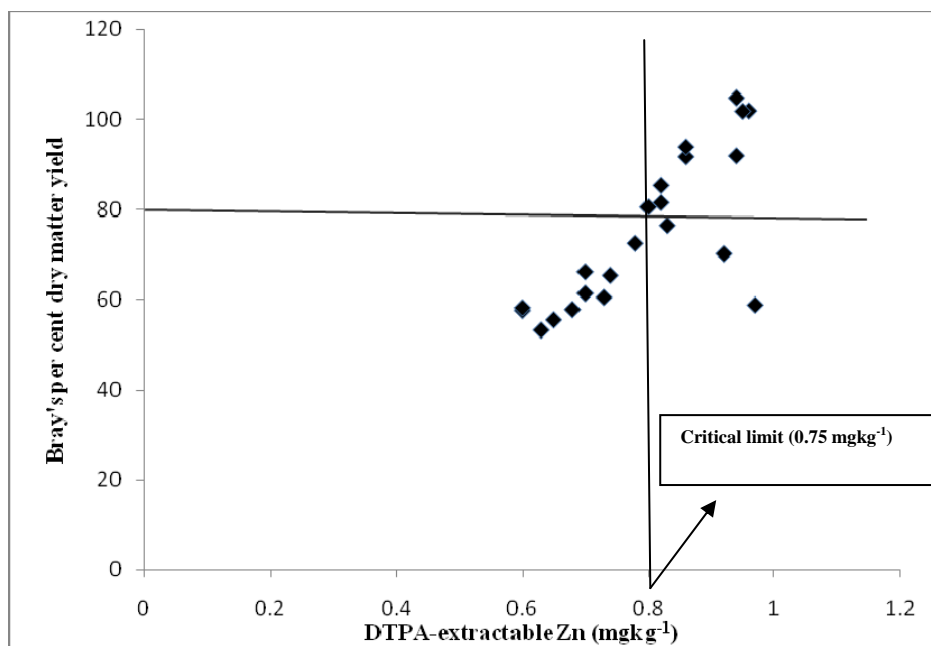


Figure 1. Scatter diagram of DTPA-extractable Zn Vs. percent dry matter yield of rice grown in soils of alluvial zone of West Bengal.

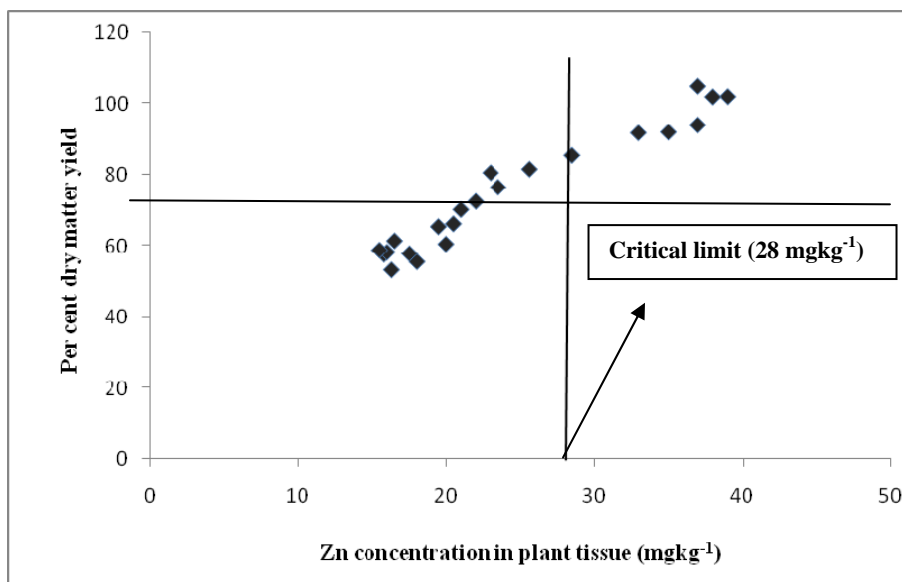


Figure 2. Scatter diagram of third leaf Zn Vs. percent dry matter yield of rice grown in soils of alluvial zone of West Bengal.