Assessment of critical limit of zinc for rice, groundnut and potato in red and laterite soils of Odisha

DR Sarangi*, D Jena and AK Chatterjee

Visva-Bharati, Sriniketan-731 236, West Bengal, India

Corresponding author e-mail: dillipsarangi99@gmail.com

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ABSTRACT

Pot culture studies were conducted taking ten different soils collected from red and laterite soils from Mayurbhanj district of Odisha with groundnut, rice and potato as test crops to determine the critical limit of zinc (Zn) in soil and plants. The soils were acidic in reaction (pH 4.72-5.84), low to medium in organic carbon content and texture varied from loamy sand to silt loamy. About 50% soils were deficient in Zn. Rice, groundnut and potato received recommended dose of NPK. Each crop received seven levels of Zn varying from 0, 1.25, 2.5, 5.0, 7.5, 10 and 12.5 kg ha^{-1}. The critical level of Zn in soils and plants as determined by simple graphical method in red and laterite soils was 0.8, 0.7 and 0.7 mg kg^{-1}. The critical concentration of Zn in rice, groundnut and potato leaves was 24.5, 23 and 27 mg kg^{-1}, respectively. Maximum biomass yield (g pot^{-1}) attained its highest value (114.17, 117.68) at 7.5 kg Zn ha^{-1} in Zn deficient soils and at 5 kg Zn ha^{-1} in medium Zn content soils (115.3, 127.59) in rice and ground nut, respectively; whereas in potato, the maximum yield (457.9) was recorded when the crop received 5 kg Zn ha^{-1} level, indicating knowledge of critical concentration will help in maximizing the yield and performance of crop.

Keywords: Critical limit, groundnut, potato, rice, red and laterite soil, zinc

Red and laterite soils occupy about 7.18 million hectare, out of the total area of 15 m ha in Odisha (Jena *et al.* 2008). These soils are lighter in texture and poor in organic matter, nitrogen (N) and phosphorus (P), but medium in potassium (K). Deficiency of secondary nutrients like sulphur (S) and micronutrients like zinc (Zn), boron (B) and molybdenum (Mo) are very common in red and laterite soils (Jena *et al*. 2008). Intensive cropping with high yielding crops varieties and low use of micronutrients containing fertilizers, resulted in depletion of micronutrients from soil reserve, concentration in the edible parts of the different crops, sharp reduction in crop productivity, quality as well as animal and human health. Despite increase in fertilizer consumption and modern crop varieties, the crop response ratio in the country has gone down from 16.5 of 1950 to 6.3 kg ha^{-1} NPK in the year 2010. This decline in the productivity factor might be due to depletion of micronutrient reserve of soil (Sakal *et al.* 1996; Singh 2008, 2012; Powlson *et al*. 2011; Ali *et al.* 2013).

Rice is the main crop of Odisha in *kharif* followed by groundnut in rabi season grown under residual moisture condition, whereas potato is grown after *kharif* rice in irrigated command areas. Among micronutrients, Zn nutrition got special importance because of its wide spread deficiency (23 to 54 %) in soils in Assam, Jharkhand, Chhattisgarh, Uttarkhand, Odisha and West Bengal (Singh *et al*. 2006). Based on several field and green house experiments, Singh *et al.* (2006) reported the critical value of Zn @ 0.6 mg kg^{-1} in soil. Soils with available nutrient status below the critical limit are likely to be deficient and sensitive crops grown on these soils. would show deficiency symptoms and respond to addition of that deficient nutrient. Results of field studies revealed that rice significantly responded to Zn application in acid and alkaline soils (Tandon 1992; Singh and Agarwal 2007). However the critical limit of Zn presently followed is of general one and no specific limit is available in literature for red and laterite soils. With this background the present study was undertaken to determine the critical limit of Zn for rice, groundnut and potato crops for making micronutrient fertilization more rational, particularity in red and lateritic soils.

MATERIALS AND METHODS

Bulk soil samples from plough layer (0-15 cm) were collected from five different blocks (10 different locations) of Mayurbhanj district of Odisha. Samples were air dried, grinded and passed through 2 mm sieve before keeping in air tight polybags for analysis. Soil particle size was measured using the protocol of Bouyoucos (1962), soil pH by glass electrode as per Jackson (1973), organic carbon (OC) by wet digestion method of Walkley and Black (1934) and cation exchange capacity by Schollenberger and Simon (1945). Available Zn content in soil was estimated by Atomic Absorption Spectrometer using DTPA extractant (Lindsay and Norvell, 1978). The physico-chemical properties of the soil are considered to be important factors for determining the availability of Zn in soils and plants. The results revealed that pH of the soils varied from 4.72 to 5.84 with mean value of 4.95 (Table 1). Except Agria, the pH of other nine sites was below 5.0. As the acid soils are rich in DTPA-Zn, plants do not suffer from Zn deficiency. The soil texture varied from loamy sand to silt loam. Higher clay content (14 %) was recorded in two soils (Rajabasa and Sathlo) whereas in other sites, it varied between 8-12 %. Similar trend was observed in silt content, whereas reverse trend was recorded for sand content. Out of ten sites, five sites have low organic carbon (OC) status and others have medium status. The results further revealed that about 50 % soils were deficient in Zn (available Zn: 0.35-1.60 mg kg^{-1}). Organic carbon content of soils was closely correlated with clay content with high correlation co-efficient (R=0.87*).

The pot culture experiments were conducted in polyethylene lined earthen pots with different soil samples (Table 1) after rinsed in 0.1 N HCl followed by deionised water. Then, seven kilogram of soil was transferred into each pot. Three pot culture experiments were conducted in a completely randomized design (CRD) with three replications on rice during kharif and on groundnut and potato during rabi 2012-13. The treatment consists of seven levels of Zn (0, 1.25, 2.5, 5.0, 7.5, 10 and 12.5 kg ha^{-1}) for each crop (rice, groundnut and potato). In rice experiment, three rice seedlings (cv. Pratiksha) of twenty five days were transplanted with recommended dose of fertilizer (N, P, K @80-40-40 kg ha^{-1}). In groundnut and potato experiments, four seeds of groundnut (cv. AK 12-24)

Table 1. Physico-chemical properties of soils used in pot culture study

Sl. No.	Locations	pH	Organic carbon (g kg-1)	Sand(%)	Silt(%)	Clay (%)	Textural class	CEC[Cmol (p+)kg-1]	(mg kg^{-1})		
									Zn	B	S
1	Balidhia	4.9	5.0	72	19	9	LS	38	0.45	0.35	5.0
2	Paikabasa	4.8	5.3	66	24	10	L	4.2	0.90	0.72	8.0
3	Patisari	4.9	6.6	63	25	12	L	4.5	0.58	0.80	10.0
4	Jadunathpur	4.9	3.5	72	20	8	LS	3.7	1.50	0.42	7.5
5	Kaliana	4.7	4.4	67	24	9	LS	4.0	1.60	0.85	6.0
6	Marangtandi	5.0	4.8	63	26	11	SiL	5.8	0.75	0.55	15.0
7	Betna	4.8	4.3	70	21	9	LS	3.8	0.35	0.34	3.0
8	Rajabasa	4.9	6.8	58	28	14	SiL	5.7	0.52	0.81	16.0
9	Santhilo	5.0	0.68	55	31	14	SiL	5.6	0.38	0.53	12.5
10	Agria	5.8	4.8	67	23	10	LS	6.0	0.65	0.57	14.0
Range	4.7-5.8	3.5-6.8	55-72	19-31	9-14			3.7-6.0	0.35-1.60	0.34-0.85	5.0-16.0
Mean	4.95	5.2	65.3	24.1	10.6			4.71	0.76	0.59	9.7
SD	0.3	1.1						0.94	0.44	0.19	4.50

L= loam; LS= loamy sand; SiL= sandy loam and potato (cv. Kurfijyoti) seeds were sown with recommended dose of fertilizer @ 20-40-40 and 120-60-90 kg NPK ha^{-1}, respectively. The crops received reagent grade of fertilizer through urea, KH_2PO_4 and KCl. Required quantity of zinc sulphate was thoroughly mixed with soil before transplanting/sowing, whereas watering (with deionized water) and plant protection measures were taken, as and when necessary. The rice plants were harvested at pre-flowering stage, whereas groundnut and potato plants were harvested at maturity. The plant, pod and tuber samples were washed with acidified solution, rinsed with deionised water, dried at 65 °C in a hot air oven and dry matter yield were recorded. The third leaf samples, collected at 30 days of growth, were processed and kept for analysis. The dry powered plant samples were digested in a mixture of 10:4:1 of HNO_3; $HClO_4$; H_2SO_4 on a hot plate and Zn concentration was determined using AAS. The critical limit for Zn of soil and plants were determined by plotting the Bray's percent yield against available Zn in soil or its concentration in plants (Cate and Nelson, 1965). Bray's per cent yield=(yield in control/yield at optimum nutrient treatment) × 100. Simple correlation was carried out to establish the relationships between nutrient and soil properties (Snedecor and Cochran 1994). The values were mentioned as mean and standard deviation (SD) values and significance was established as $p<0.05$.

RESULTS AND DISCUSSION

The relationship between soil test level and relative yield vary considerably, and the shape of the relationship is relatively consistent. The available Zn content in soils ranged from 0.35-1.6 with mean value of 0.76 mg kg^{-1}. The per cent dry matter yield of rice in Zn treated soils ranged from 63.7-102.6 with mean value of 78.48. These values are close to the critical level of Zn (0.83 mg kg^{-1}) as observed by Muthukumararaja and Sriramachandrasekharan (2012).

The plot of Brays per cent yield against available Zn in soil revealed the critical concentration of Zn as 0.8 mg kg^{-1} in soils for rice crop (Fig. 1). The Zn concentration in third leaf of rice plant ranged between 13-28 mg kg^{-1} (fig. 4). The plot of Brays per cent yield against Zn concentration in leaf revealed that the critical concentration of Zn for rice was 24.5 mg kg^{-1}. Similar to our findings, Sakal *et al.* (1984) reported

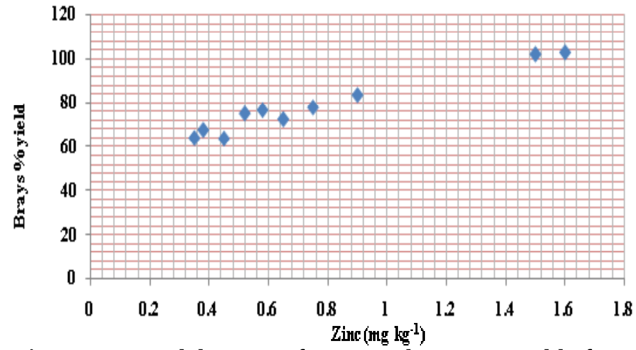

Fig. 1. Scattered diagram of per cent dry matter yield of

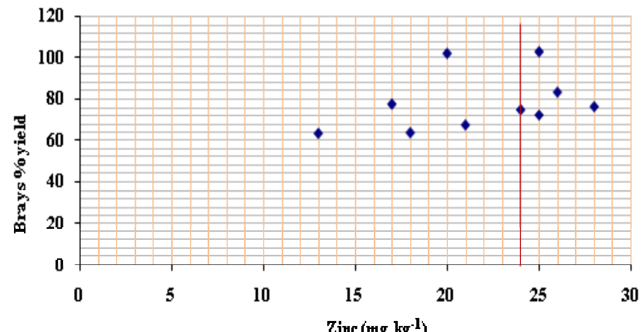

Fig.4. Scattered diagram of per cent dry matter yield and Zn content in 3rd leaf of rice

the critical limit of DTPA-Zn and plant tissue Zn for rice in Sub- Himalayan hill and forest soils 0.76 and 21.5 mg kg^{-1}, respectively, below which appreciabl response to Zn application was observed. Similarly, the critical concentration of Zn (mg kg^{-1}) in alluvial soils of West Bengal was established at 0.75 for rice and 28.0 in the rice plant tissue (Mahata *et al.* 2012), whereas for acidic soils of Arunachal Pradesh the corresponding values were 0.78 and 27 (Debnath *et al.* 2014). Das and Saha (1999) reported lower DTPA-Zn critical value (0.60 mg kg^{-1}) for rice and wheat for acid soils of West Bengal.

The per cent dry matter yield of groundnut in Zn treated soils ranged from 45.1-88.0 with mean value of 73.56. The plot of Brays per cent yield against available Zn in soil revealed the critical concentration of Zn as 0.7 mg kg^{-1} in soils for groundnut crop. The Zn concentration (mg kg^{-1}) in leaf of groundnut plant ranged between 13 to 28. The plot of Brays per cent yield against Zn concentration in leaf revealed that the critical concentration of Zn for groundnut was 23 mg kg^{-1} (Fig. 2 & Fig. 5).

The per cent dry matter yield of potato in Zn treated soils ranged from 73.4-86.8 (mean=79.76).

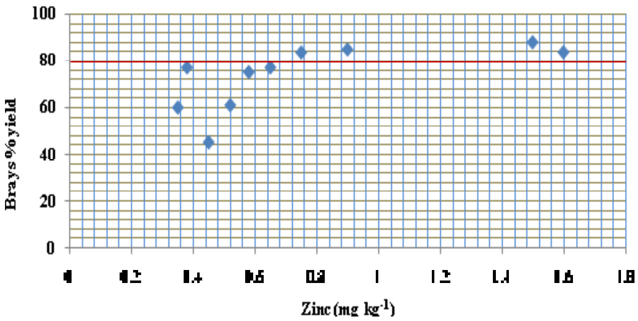

Fig. 2. Scattered diagram of per cent dry matter yield of groundnut and available Zn in soil

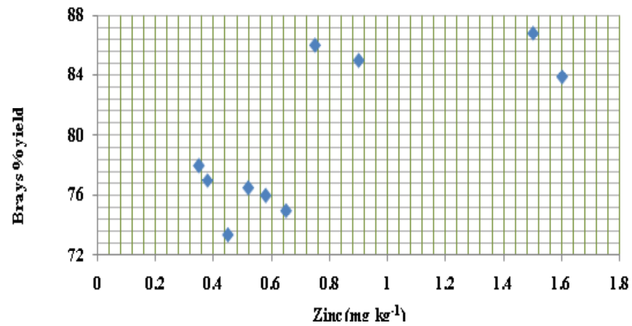

Fig. 3. Scattered diagram of per cent dry matter yield of potato and available Zn in soil

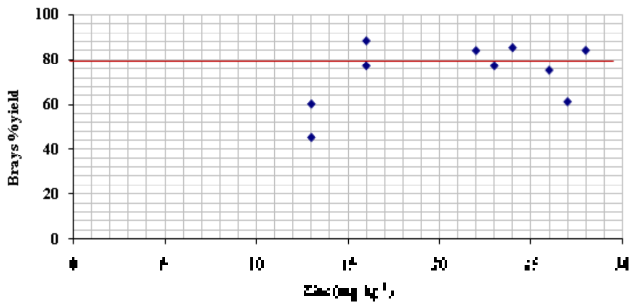

Fig. 5. Scattered diagram of per cent dry matter yield and Zn content in 3rd leaf of groundnut

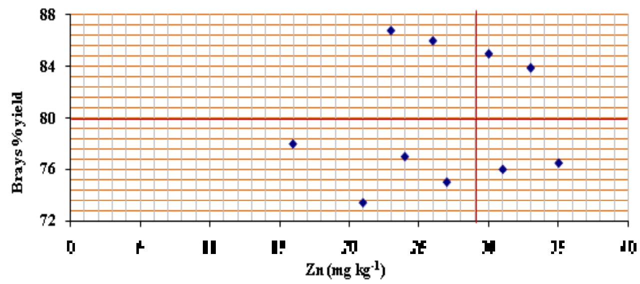

Fig. 6. Scattered diagram of per cent dry matter yield and Zn content in 3rd leaf of potato

Brays per cent yield plot against available Zn in soil revealed the critical concentration of Zn in soils for potato crop to be 0.7 mg kg^{-1}. The Zn in third leaf of potato plant had Zn concentration in the range of 21-35 mg kg^{-1}, whereas the plot of Brays per cent yield against Zn concentration in leaf revealed that the critical concentration of Zn for potato was 27 mg kg^{-1}(Fig. 3 & Fig. 6).

Plants require zinc in traces, but it is critical for key functions like photosynthesis, protein synthesis, phyto-hormone synthesis, seeding vigor, sugar formation, fight against stress and disease (Rattan *et al*. 2009). It is estimated that around half of the world's agricultural soils are deficient in zinc, leading to low crop production and lower nutritional value of products. The soils used in present pot culture study were 50 % deficient, 30 % medium and 20 % high in DTPA-Zn. With application of zinc fertilizer, the biomass yield was increased sharply, attained its highest value at 7.5 Zn ha^{-1} dose in Zn deficient soils and at 5 kg ha^{-1} in medium Zn content soils in case of rice (Table 2), whereas in groundnut and potato, the maximum yield was recorded when the crop received 5 kg Zn ha^{-1} (Table 3 & table 4). However, average dry matter yield increased with increasing level of Zn application upto 2.5 mg kg^{-1} in Zn deficient soils in alluvial soils of West Bengal (Mahata *et al*. 2012) and acid soils of Arunachal Pradesh (Debnath *et al*. 2014).Dose of 2.5 kg Zn ha^{-1} for rice, groundnut and potato was found optimum for high Zn content soils. The data further revealed that at optimum level of zinc fertilizer application, the biomass yield was increased by 26.7 % in rice, 63.8 % in groundnut and 23.4 % in potato over control crop. The average response to Zn application in rice in Zn deficient soils and Zn adequate soils was found to be 68.5% and 19.9% in alluvial soils of West Bengal (Mahata *et al*. 2012) and 59.5 and 11.05 % in acid soils of Arunachal Pradesh (Debnath *et al*. 2014) for the respective soil types. Vanitha *et al*. (2014) observed different levels of zinc tolerance in different varieties of rice, which may be responsible for variation among different reports. For groundnut, Singh and Mann (2007) observed that application of 5 kg Zn ha^{-1} significantly increased the pod yield of groundnut in Tonk district of Rajasthan.

Based on the results, the critical limit Zn of rice was higher than groundnut and potato indicating that rice requires more Zn than the other crops in red and laterite soils. Based on the critical limit of Zn, the fertility rating and recommendations need to be modifiedfor the crops grown in red and laterite soils.

Table 2. Effect of different treatments on biomass yield (g pot $^{-1}$) and Zn concentration (mg kg $^{-1}$) in rice leaf

Soil	DTPA Zn (g kg^{-1})	Biomass yield (g pot^{-1}) Levels of zinc (kg ha^{-1})							Bray's P yield (%)	Zn content 3rd leaf in control (g kg^{-1})
		0	1.25	2.50	5.0	7.5	10	12.5		
1	0.45	80.0	110.0	115.0	118.5	125.5	120.0	118.0	63.7	13
2	0.90	90.0	95.0	108.0	107.5	107.0	105.0	104.0	83.3	26
3	0.58	94.5	108.5	115.0	123.5	120.0	115.0	100.0	76.5	28
4	1.50	112.0	110.0	110.0	109.0	107.0	105.0	103.5	101.8	20
5	1.60	115.0	112.0	110.5	110.0	108.0	106.0	104.5	102.6	25
6	0.75	90.0	99.0	112.0	115.9	114.0	109.0	108.5	77.7	17
7	0.35	75.5	100.0	113.0	116.0	117.8	110.0	109.0	64.0	18
8	0.52	90.0	110.0	118.0	120.0	110.0	110.0	108.0	75.0	24
9	0.38	80.0	108.0	115.5	118.0	118.4	108.0	107.0	67.6	21
10	0.65	83.0	110.0	113.0	114.6	114.0	109.0	108.0	72.4	25
Range	0.38-1.60	75.5-115.0	95.0-112.0	108.5-118.0	107.5-120.0	107.0-125.5	105.0-120.0	100.0-118.0	63.2-102.6	13-28
Mean	0.77	91.0	106.3	103.1	115.3	114.17	109.7	107.1	78.48	
SD		13.24	5.92	2.99	5.12	6.25	4.66	4.78		4.71

Table 3. Effect of different treatments on biomass yield (g pot-1) and Zn concentration in groundnut leaf

Soil	DTPA Zn (mg kg^{-1})	Biomass yield (g pot^{-1}) Levels of zinc (kg ha^{-1})							Bray's P yield (%)	Zn content in 3rd leaf in control (mg kg^{-1})
		0	1.25	2.50	5.0	7.5	10	12.5		
1	0.45	60.4	71.3	84.2	133.9	129.4	130.0	93.4	45.1	13
2	0.90	110.5	125.0	130.0	129.0	125.0	109.0	90.0	85.0	24
3	0.58	97.5	118.0	129.5	130.0	120.0	115.0	98.5	75.0	26
4	1.50	112.6	128.0	125.0	123.0	108.0	106.5	89.4	88.0	16
5	1.60	109.0	130.0	124.0	119.0	110.0	98.0	88.0	83.8	28
6	0.75	108.0	120.0	128.0	129.0	115.0	107.0	95.0	83.7	22
7	0.35	76.2	108.0	117.0	125.0	127.0	112.0	100.5	60.0	13
8	0.52	80.0	111.0	123.0	131.0	114.8	112.0	100.0	61.0	27
9	0.38	75.0	108.0	120.0	128.0	113.8	105.0	97.5	77.0	16
10	0.65	98.6	112.0	125.0	128.0	113.8	105.0	97.5	77.0	23
Range	0.38-1.60	60.4-112.6	71.3-125.0	84.2-130.0	119.0-133.9	108.0-129.4	98.0-130.0	93.4-100.5	45.1-88.0	13-28
Mean	0.77	92.78	113.13	120.57	127.59	117.68	109.95	94.98	73.56	
SD		18.44	16.75	13.4	4.25	7.31	8.49	4.56		5.78

Table 4. Effect of different treatments on biomass yield (g pot-1) and Zn concentration in potato leaf

Soil	DTPA Zn (mg kg^{-1})	Biomass yield (g pot^{-1}) Levels of zinc (kg ha^{-1})							Bray's P yield (%)	Zn content in 3rd leaf in control (mg kg^{-1})
		0	1.25	2.50	5.0	7.5	10	12.5		
1	0.45	345	414	436	469	459	420	332	73.4	21
2	0.90	391	405	440	460	445	406	315	85.0	30
3	0.58	353	415	435	463	458	424	330	76.0	31
4	1.50	395	402	455	453	442	380	306	86.8	23
5	1.60	386	408	460	402	399	381	304	83.9	33
6	0.75	404	428	455	470	452	415	330	86.0	26
7	0.35	359	414	433	459	460	425	331	78.0	16
8	0.52	360	420	457	460	470.5	435	340	76.5	35
9	0.38	355	417	436	461	455	427	327	77.0	24
10	0.65	362	422	460	482	462	445	335	75.0	27
Range	0.38-1.60	353-404	402-422	433-460	402-482	399-470.5	380-445	304-340	73.4-86.8	21-35
Mean	0.77	371	414.5	446.7	457.9	450.25	415.8	325	79.76	
SD		20.79	7.91	11.52	21.19	19.79	21.35	12.31		5.83

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