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Different fractions of zinc and their relationship with physico-chemical properties in red and lateritic soils of Birbhum district, West Bengal

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Abstract
Distribution of different zinc forms and its relationship with physico-chemical properties in three blocks under red and lateritic soils of West Bengal were studied. Sequential extraction scheme was used to fractionate Zn into Water Soluble and Exchangeable (WE), Organic bound (Org), Amorphous sesquioxide (Amor), Crystalline Sesquioxide (Cry), Manganese bound (Mn) and Residual zinc (Res). Results of the study indicated that the most of soils were sandy clay loam in texture with strong to moderately acidic pH (4.35-6.94). The organic carbon content of these soils ranged from 0.25 to 0.76 percent. DTPA-zinc varied from 0.37 to 1.28 mg kg^{-1}. Total zinc was calculated as the sum of all the pools and it varied in between 25.97 and 54.46 with an average of 39.51 mg kg^{-1}. The distribution of Zn in the soils based on average concentrations was in the order of 25.49 mg kg^{-1} Res Zn (64.51%)> 5.05 mg kg^{-1} Mn-Zn (12.7%) > 4.96 mg kg^{-1} Cry-Zn (12.5%)> 2.61 mg kg^{-1} Amor-Zn(6.6%)> 1.04 mg kg^{-1} Org-Zn(2.6%) >0.48 mg Kg^{-1} WE-Zn (1.21%). Correlation analysis showed all the fractions were significantly and negatively correlated with soil pH, while as a positive relation with organic carbon (OC), DTPA-Zn and clay content. All the fractions were significantly and positively correlated among themselves, indicating existence of dynamic equilibrium among the different pools of zinc.

Keywords: Zinc fraction, DTPA-Zn, organic carbon, correlation analysis

Introduction
Zinc is known to occur in soil in a number of discrete chemical forms differing in their solubility and thus availability to plants (Sarkar and Deb, 1982) [43]. Proper understanding of fractions which control the distribution of Zn between active soil constituents and soil solution is fundamental to understand chemistry of zinc in soil Zinc exists in five distinct pools in soils *viz*., water soluble, exchangeable, adsorbed, chelated or complexed zinc (Viets, 1962) [58].

The equilibrium among the different pools is influenced by pH and concentration of zinc and other cations, particularly iron and manganese. The readily available zinc forms *viz*., water soluble, exchangeable and chelated zinc forms were in reversible equilibrium with each other (Viets, 1962) [58]. Several workers observed a dynamic equilibrium among these fractions in soil and contribute zinc differently to the available pool of zinc in soils. Therefore, knowledge about their extent of distribution and their relationship with soil properties would help in assessing the zinc availability in soils. In view of the above facts, the information available in respect of available zinc status, distribution of various fractions of zinc and their relationship with properties in soils of Birbhum district is lacking. Hence, the investigation was carried out with the following objectives includes,to study the different fractions of zinc in red and lateritic soils of Birbhum district and to study the relationship between fractions of zinc and physico-chemical properties in red and lateritic soils of Birbhum district.

Thirty soil samples (0-15cm) were collected from each three blocks namely Md. Bazar, Nalhati and Bolpur of Birbhum district and these soils were analysed for the various physico-chemical properties following the standard procedures. Particle size analysis was carried out by Hydrometer method using sodium hexa metaphosphate as a dispersing agent as described by Bouyoucos (1927) [6]. Soil texture was identified using textural diagram given by International Society of Soil Science. Soil reaction (pH) of the samples was measured in 1:2.5 soil: water suspension with a digital glass electrode pH meter (Jackson 1973) [23]. Electrical conductivity was measured using conductivity bridge as outlined by Jackson (1973) [23] under suitable measuring conditions. Walkley and Black's (1934) [59] wet oxidation method was used for determination of organic carbon (OC).

Available nitrogen was estimated by alkaline $KMnO_4$ (Subbaiah and Asija, 1956) [54]. Available phosphorus was extracted with Bray No-1 solution as extractant (Bray, 1945) [7] and using spectrophotometer at wave length of 660 nm. Available K was extracted with neutral normal ammonium acetate and determined using flame photometer (Jackson, 1973) [23]. Plant available (DTPA–extractable) zinc in soils was extracted using DTPA extractant (pH 7.3) at 1:2 soil to extractant ratio as described by Lindsay and Norwell (1978) [29].

Zn fractions were determined using a modified sequential extraction procedure of Murthy (1982) [33] proposed by Mandal *et al*., (1986) [30]. The Zn pools in soils were divided into seven fractions including residual and total Zn forms in soils, except residual and total, were extracted from soils using 50 mL plastic centrifuge tubes with individual extracting solutions (see Table 1.2) and shaken in a rotary shaker at room temperature (25 ± 2 °C).The supernatant solutions obtained from each successive stage of extraction were centrifuged at 3,500 rpm for 15 min, decanted and filtered with Whatman No. 42 filter paper. It was absolutely crucial to prevent any delay between adding the extraction solutions and starting shaking them. Three replicates all sequential extractions and analyses were performed for each soil sample. The concentration of zinc in the extractant was determined by Atomic Absorption Spectrophotometer (Page *et al*., 1982) [34]. The total Zinc in soil was determined by using Atomic Absorption Spectrophotometer after HF and $HClO_4$ digestion method (Page *et al*., 1982) [34]. Residual fraction is obtained by subtracting total zinc fractions from all other fractions.

Table 1: Zinc sequential fractionation procedures.

Fractions	Reagents	Soil(g): Solution(ml)	Conditions	References
1. Water soluble + exchangeable (WE)	1 M $(NH_4)OAc$ (pH7.0)	5:20	Shake 1 h	Murthy (1982) [33] modified by Mandal & Mandal (1986) [30]
2. Organically complexed(Org)	0.05 M $Cu(OAc)_2$	5:20	Shake 1 h	""
3. Amorphous Sesquioxide (Amor)	0.2 M $(NH_4)_2C_2O_4{\cdot}H_2O$ + 0.2 M $H_2C_2O_4$ (pH3.0)	5:20	Shake 1 h	""
4. Crystalline sesquioxide (Cry)	0.3 M sodium citrate + 1.0 M $NaHCO_3$+ 1 g $Na_2S_2O_4$,(CBD)	5:20	Boiling water bath,10 min, stir occasionally, keep on water bath, (70–80 °C), 15 min, stir occasionally	""
5. Manganese oxide (Mn)	0.1M $NH_2OH{\cdot}HCl$ (pH 2.0)	5:50	Shake 30 min	Chao (1972) [9]

The results obtained in respect of soil properties were subjected for simple correlation analysis and the observed 'r' values were tested at 1% and 5% level of significance (Sundarraj *et al.,* 1972) [55].

Results and discussion

Physico-chemical properties of soil (Table 2)

The mechanical composition of samples collected from three different blocks of Birbhum district indicated that the texture varied from sandy loam to sandy clay loam texture. Sand was the dominant fraction in these soils, which might be due to high rainfall and the parent material from which the soil was derived. The results of the study was in conformity with the findings of Sathyanarayana and Biswas (1970) [44] who reported that soils developed from granite type of parent material had a coarse texture. Similar observation was made Kumar (2017) [27] in Soils of Chamarajanagar district, Karnataka.

The pH of the surface soils under present investigation showed that most of the soils are strong to moderately acidic in nature. Acidic pH of the soils might be attributed to the type of parent material from which these soils have been derived and leaching of basic cations. This is in agreement with the findings of Chakravarti *et al*., (1957) [8], who stated that soils of Birbhum districts are acidic in nature.

Electrical conductivity in the soils under study and was found to be normal with respect to plant growth. The electrical conductivity values were low and soils are non-saline in nature. Same trend observed in soils of all three blocks, which may be due to low in salt concentration as observed by Chakravarti *et al*., (1957) [8] and Ray *et al*., (2012) [40].

Soil organic carbon status in soils of three different blocks ranged from 0.24 to 0.73%, 0.28 to 0.76% and 0.25 to 0.81% respectively. Soils from Nalhati blocks showed high amount of organic carbon content. Organic carbon content in most of the soil showed low to medium in range. This might be due to continuous cultivation and scarce application of FYM. High temperature and good aeration in the soil increased the rate of oxidation of organic matter resulting reduction of organic carbon content as observed by Deshmukh (2012) [5], Pandit *et al*., (2016) [36] and Das *et al*., (2010) [14].

The overall available P of the study area was noted from 12.04 to 42.4 kg ha^{-1} with a mean value of 27.09 kg ha^{-1}, majority of the soils under study showed low available P status.The low available P status in these soils might be due to acidic nature of soil. This result agrees with observations of Deshmukh (2012) [5], Pandit *et al*., (2016) [36] and Das *et al*., (2010) [14].

The DTPA-extractable zinc content in the surface soils under study, varied from 0.37 to 1.28 mg Kg^{-1} with an average value 0.856 mg kg^{-1}. Considering the soil test rating for DTPA-extractable Zn (<0.6 mg kg^{-1} as deficient, 0.6-1.2 mg kg^{-1} as sufficient and >1.2 mg kg^{-1} high level) as critical limit for Zn deficiency (Lindsay and Norvell, 1978) [29]. The overall samples were found to be 18% in deficient, 67% in sufficient and only 13% samples were found to be high level in available Zn content in soil.

Soils of Nalhati block were found to contain higher amount of DTPA-extractable zinc compared to Md. Bazar and Boplur block soils due to the high organic carbon content as noticed in the present study. A similar trend was observed by Singh *et al*., (1988) [49] and Sharma and Lal (1992) [46]. The similar results were observed by Tiwari and Mishra (1990) [59], Krishnamurthy and Srinivasamurthy (2001) [26] and Chidanandappa *et al*., (2008) [12], and Kumar (2017) [27].

Distribution of different forms of Zinc

The results given in the table 3 revealed that the water soluble and exchangeable zinc content was found to be least (1.0 percent) among the zinc fractions; it ranged from 0.28 to 0.83, 0.25 to 0.76 and 0.21 to 0.70 mg kg^{-1} in the surface soils of Md. Bazar, Nalhati and Bolpur respectively. This might be due to high zinc buffering capacity of soils which resulted in low amount of WE zinc fraction, Deb (1997) [15]. Similar results were found by Kumar and Babel (2011) [28] and Ramzan *et al*., (2014) [39]. The contribution of organic bound fraction of Zn (0.48 to 2.17 mg kg^{-1}) was next to amorphous sesquioxide (Amor) bound fraction amongst the non-residual fractions,The mean value of organically bound zinc was found high in the soils of block Nalhati, and was lowest in soils of Bolpur block (1.04 mg Kg^{-1}), it may due to high and low values of OC content in Nalhati block and Bolpur respectively, These results in agreement with the findings of Mandal and Mandal (1986) [30]. Similar results were also reported by Tehrani (2005) [56]; Bahera *et al*., (2008); Safari *et al*., (2009) and Ramzan *et al*., (2014) [39].

The percentage of amorphous sesquioxide bound (Amor) forms of Zn was 6.6 among the entire Zn fractions studied. This fraction of Zn was varied in 1.85 to 4.01, 1.59 to 4.03 and 1.14 to 4.02 mg kg^{-1} in respective blocks. Md. Bazar block showed highest Amor fraction among three blocks. This may be attributed to greater ability of amorphous sesquioxide to adsorb Zn because of their high specific surface area, Devis and Leckie (1978). Water logging may cause an increase in the Amor forms of native soil (Mandal and Mandal, 1986) [30]. Similar results were observed by Tehrani (2005) [56]; Bahera *et al*., (2008) and Safari *et al*., (2009).

Amongst the non-residual fractions, the crystalline sesquioxide bound (Cry) fraction was found to be the major fraction of Zn, it varied from (2.99 to 9.28 mg kg^{-1}) in overall study area, among three blocks Nalhati block showed high value of Cry fraction (10.89 mg Kg^{-1}), Higher Zn concentrations of these stable fractions denote their importance as the storage fractions for soil Zn, although their solubilities will determine how available they are for plant uptake. The results are quite near to the results of by Singh *et al*., (1999) [48] who reported that oxides bound Zn ranged from 2.05 to 3.40 mg kg^{-1} in some rice growing red soils of India. The above results are also in conformity with the reports of Alvarez *et al*., (2001) [1], Bashir *et al*., (2007) [3] and Chen *et al*., (2009) [10].

Among the soils studied the content of crystalline sesquioxide bound zinc was more in soils compared to Amor forms in Birbhum district. This suggested that more of the free iron oxide may be in crystalline form also observed by Pal *et al*., (1997) [35]. The easily reducible manganese bound zinc fraction varied from 3.14 to 7.36, 3.38 to 7.55 and 3.19 to 7.31mg Kg^{-1} respectively. Both the content and percent contribution of this fraction to total zinc was next to residual zinc, highest amounts of easily reducible manganese oxide bound form of zinc was observed when compared with Cry zinc fraction indicating that easily reducible manganese oxide might be of greater importance than Fe and Al in these soils. Singh *et al*., (1988) [49] also observed similar results.

Residual zinc was the dominant fraction among all the zinc fractions studied and agrees with the findings of Edward Raja and Iyengar (1986) [20] and Iyengar and Deb (1977) [22]. The greater percentage of Zn in the residual fraction likely indicated its greater tendency to become unavailable in the soil. Similar results of residual Zn consisting of large proportions of total Zn was also reported by Singh, (2011) [50] and Kamali *et al*., (2010) [24]. The total zinc content in the soils of three blocks under study ranged from 25.73 to 51.80, mg kg^{-1}. Higher concentration of total zinc may be due to the increase in clay content as reported by Singh and Abrol (1986) [47] and Sharma *et al*., (2002) [45].

Relationship between zinc fractions and physico-chemical properties

Correlation analysis in between Zn fractions and physicochemical properties was carried out and r values mentioned in Table 4. Water soluble zinc was correlated significantly and negatively with EC (r= -0.345**), pH and positively with OC (r=0.167**), Clay (r=0.217**) and DTPA-Zn (r=0.249**) in soils of Birbhum district. The negative correlation with pH indicating that at higher pH, insoluble calcium zincate or higher oxides of zinc will be formed, and zinc bound in these forms does not come into the solution easily. Similar observations were recorded by Hazra *et al*., (1987) [21], Pal *et al*., (1997) [35] and Prasad and Sakal (1988) [37]. Positive correlation of this fraction with OC also reported by Dhane and Sukla (1995) [19] and Edward Raja and Iyengar, (1986) [20].

Organic matter bound zinc was correlated significantly and positively with organic carbon content in soils under study(r=0.425**). Organic matterprovides exchange sites for the adsorption of zinc. Similar relationship was reported by Bharath Singh *et al*., (1987) [5] and Prasad and Sakal (1988) [37] and (Pal *et al*., 1997) [35]. Organic matter bound zinc was correlated significantly and positively with clay content in soils under study, similar relationship was reported by Soltani *et al*., (2015) [52] and Spalbar *et al*., (2017) [53], whereas Org fraction showed significant negative correlation with soil pH (r= -0.217**), Ramzan *et al*., (2014) [39] reported similar results in his studies.

Amorphous sesquioxide bound zinc was correlated significantly and negatively with pH (r= -0.285**) and significantly and positively with clay content (r =0.312**), whereas a non-significant positive correlation showed between Amor fraction and soil EC and OC. This observation agrees with findings of Spalbar *et al*., (2017) [53], and Wijebandara (2007) [60].

Crystalline sesquioxide bound (Cry) zinc was correlated significantly and negatively with soil pH and positively with clay content in soils of Birbhum district. This is in agreement with the research conducted by Wijebandara *et al*., (2011) [61], Ashraf *et al*., (2012) [2], Spalbar *et al*., (2017) [53]. Whereas Cry fraction showed significant and positive correlation with soil OC (r=0.283**) in soils of Birbhum district, this is agreement with observation made by Prashantha (2011) [38].

Manganese oxide bound (Mn) zinc was correlated significantly and positively with clay content in soils of all three blocks, whereas it is positively correlated soil OC (r=0.189**), it is similar to the observation was made by Soltani *et al*., (2015) [52] and Wijebandara (2007) [60].

Significant negative correlation of residual zinc with pH showed in all three blocks, similar observation was made by Mukesh (2013) [32] and Spalbar *et al*., (2017) [53], Residual zinc showed significant and positive correlation with organic carbon (r=0.134**) and clay content (r=0.341**), the positive correlation with organic carbon pointed out that zinc availability in soils would increase with increase in organic matter content, this is in conformity with the findings of Pal *et al*., (1997) [35] and Wijebandara *et al*., (2011) [61]. A non-significant positive correlation observed residual zinc and soil

EC in all three blocks, this result showed agreement with observation of Spalbar *et al*., (2017) [53].

Total zinc showed significant negative correlation with pH in soils from all three blocks of Birbhum district. These observations are in line with those reported by Sankar and Murugapan (1995) [42]. A highly Significant and positive correlation between total zinc and organic carbon was observed in the soils of study area. Similar finding was also reported by Sankar and Murugapan (1995) [42]. A significant positive correlation observed between total zinc fraction soil clay content observed in soils under study, similar observation showed in the studies of Mukesh (2013) [32] and Wijebandara (2007) [60].

A positive correlation was seen between DTPA-extractable zinc and water soluble, easily reducible manganese bound zinc, organic matter bound zinc, amorphous sesquioxide zinc and crystalline sesquioxide zinc indicates the influence of these fractions on availability of zinc in soils, this is evident from the positive relationship of available zinc with these fractions. This kind of relationship was reported by Chidanandappa (2003), Dhane and Shukla (1995) [19], Edward Raja and Iyengar (1986) [20] and Singhal and Rattan (1995) [51].

Table 2: Chemical characteristics in the soils of Birbhum district.

BLOCK		pH	EC (dSm^{-1})	Organic C (%)	Available N (Kg/ha)	Available P (Kg/ha)	Available K (Kg/ha)	DTPA-Zn (mg/Kg)	Textural Class
	Range	4.35-5.84	0.01-0.08	0.24-0.73	117.8-376.32	9.08-43.31	122.3-300.2	0.33-1.30	SCL
Md. Bazar	Mean	4.90	0.04	0.47	285.17	26.38	220.31	0.84	
Nalhati	Range	5.91-6.94	0.01-0.07	0.28-0.76	175.62-401.41	18.02-42.89	193.13-357.26	0.35-1.26	SCL
	Mean	6.47	0.03	0.56	298.55	29.72	271.67	0.88	
Bolpur	Range	4.66-5.75	0.01-0.07	0.25-0.81	234.15-409.77	9.21-41.0	138.92-380.73	0.45-1.28	SCL
	Mean	4.92	0.03	0.49	347.05	25.8	286.28	0.85	

Table 3: Different forms of zinc in soils of Birbhum district

Block		WE-Zn (mg/Kg)	Org-Zn (mg/Kg)	Amor-Zn (mg/Kg)	Cry-Zn (mg/Kg)	Mn-Zn (mg/Kg)	Residual Zn (mg/Kg)	Total Zn (mg/Kg)
Md. Bazar	Range	0.28-0.83	0.43-2.28	1.85-4.01	3.01-9.74	3.14-7.36	11.25-36.92	23.3-51.8
	Mean	0.49	1.02	2.81	5.17	4.89	24.90	39.37
Nalhati	Range	0.25-0.76	0.49-2.03	1.59-4.03	3.01-10.89	3.38-7.55	16.10-36.86	28.90-53.27
	Mean	0.49	1.07	2.54	5.21	5.21	25.26	39.73
Bolpur	Range	0.21-0.70	0.42-2.12	1.14-4.02	2.95-7.23	3.19-7.31	13.99-41.11	25.73-58.27
	Mean	0.46	1.04	2.50	4.50	4.50	25.98	39.43

Table 4: Inter-relationship (correlation coefficient) between physico-chemical properties and different forms of zinc in soils of Birbhum district.

Parameters	WE-Zn (mg/Kg)	Org-Zn (mg/Kg)	Amor-Zn (mg/Kg)	Cry-Zn (mg/Kg)	Mn-Zn (mg/Kg)	Residual Zn (mg/Kg)	Total Zn (mg/Kg)
pH	-0.171**	-0.202**	-0.285**	-0.245**	-0.312	-0.225**	-0.246
EC	-0.345**	0.138	0.056	0.264	0.120	0.187	0.270
OC	0.167**	0.425**	0.143	0.283**	0.189**	0.134**	0.476**
Clay	0.217**	0.346	0.312**	0.395**	0.435**	0.341**	0.441**
DTPA-Zn	0.249**	0.171**	0.213**	0.241**	0.273**	0.199**	0.421**

*. Correlation is significant at the 0.05 level. **. Correlation is Significant at the 0.01 level

References

1. Alvarez JM, Novillo J, Obrador A, Lopez-Valdivia LM. Mobility and leachability of zinc in two soils treated with six organic zinc complexes. Journal of Agriculture Food Chemistry. 2001; 49:3833-3840.
2. Ashraf MA, Maah MJ, Yuso I. Chemical Speciation and potential mobility of heavy metals in the soil of former tin mining catchment. The Scientific World Journal. 2012; 10:1-11.
3. Bashir F, Shafique T, Kashmiri MA, Tariq M. Contents and fractionation of heavy metals in soils irrigated with sewage effluents. Journal of Chemical Society of Pakistan. 2007; 29:1-12.
4. Behera KS, Singh, Dwivedi BS, Singh S, Kumar K, Rana DS. Distribution of fractions of zinc and their contribution towards availability and plant uptake of zinc under long-term maize and wheat cropping on an inceptisol. Australian Journal of Soil Research. 2008; 46:83-89.
5. Bharath Singh, Mahendra Singh, Dang YP. Distribution of forms of zinc in some soils of Haryana. Journal of Indian Society of Soil Science. 1987; 35:217-224.
6. Bouyoucos GJ. The Hydrometer as a new method for the mechanical analysis of soils. Soil science. 1927; 23:343-353.
7. Bray RH, Kurtz LT. Determination of total, organic, and available forms of phosphorus in soils. Soil science. 1945; 59:39-45.
8. Chakravarti P, Chakravarti S. Soils of West Bengal, Agricultural research institute, Calcutta. 1957, 23:B.
9. Chao TT. Selective dissolution of manganese oxides from soils and sediments with acidified hydroxylamine hydrochloride. Soil Science Society of American Proceedings. 1972; 36:764-768.
10. Chen Z, YeZ Li Q, Qiao J, Tian Q, Liu X. Heavy metal contents and chemical speciations in sewage-irrigated soils from the eastern suburb of Beijing, China. Journal of Food, Agriculture and Environment. 2009; 7:3-4.
11. Chidananadappa HM. Dynamics of zinc and copper in organic materials amended soils. UAS Bangalore, 2003.
12. Chidanandappa HM, Hameedulla Khan, Chikkaramappa T, Shivaprakash BL. Forms and distribution of zinc in soils under mulberry (*Morus indica* L.) of multivoltine seed area in Karnataka. Mysore Journal of Agricultural Sciences. 2008; 42(1):26-32.

13. Dadhich SK, Somani LL. Effect of integrated nutrient management in soybean –wheat crop sequence on the yield, micronutrient uptake and postharvest availability of micronutrients on typic *ustochrepts* soil. Acta Agron. Hungarica. 2007; 55(2):205-216.
14. Das A, Patel DP, Munda GC, Gosh PK. Effect of organic and inorganic sources of nutrients on yield, nutrient uptake and soil fertility of maize (*Zea mays*) - Mustard (*Brassica campestris*) cropping system. Indian Journal of Agricultural Sciences. 2010; 80(1):85-88.
15. Deb DL. Micronutrient research and crop production in India. Journal of Indian Society of Soil Science. 1997; 45(4):675-692.
16. Deb DL, Gupta GN. Effect of chelating agents on zinc diffusion in two soils. Journal of plant nutrition and soil science. 1983; 147(5):533-539.
17. Deshmukh KK. Evaluation of soil fertility status from Sangamnar area, Ahmednagar district, Maharashtra. Rasayan Journal Chemicals. 2012; 5(3):398-406.
18. Devis JA, Leckie JO. Effect of adsorbed complexing legands on trace metal uptake by hydrous oxides. Environmental Science and Technology. 1978; 12:1309-1315.
19. Dhane SS, Shukla LM. Distribution of different forms of Zinc in benchmark and other established soil series of Maharashtra. Journal of Indian Society of Soil Science. 1995; 43:594-596.
20. Edward Raja M, Iyengar BRV. Chemical pools of zinc in some soils as influenced by sources of applied zinc. Journal of Indian Society of Soil Science. 1986; 34:97-105.
21. Hazra GC, Mandal B, Mandal LN. Distribution of Zinc fractions and their transformation in submerged rice soils. Plant and Soil. 1987; 104:175-181.
22. Iyengar BRV, Deb DL. Contribution of soil zinc fractions to plant uptake and fate of zinc applied to the soil. Journal of Indian Society of Soil Science. 1977; 25:426-432.
23. Jackson ML. (Soil Chemical Analysis, Prentice Hall of India Private Limited, New Delhi, 1973.
24. Kamali S, Ronaghi A, Karimian N. Zinc transformation in a calcareous soil as affected by applied zinc sulfate, vermicompost and incubation time. Communications in Soil Science and Plant Analysis. 2010; 41:2318-2329.
25. Kizilgoz I, Sakin E. The effects of increased phosphorus application on shoot dry matter, shoot P and Zn concentrations in wheat (*Triticum durum* L.) and maize (*Zea* mays L.) grown in a calcareous soil. African Journal of Biotechnology. 2010; 9(36):5893-5896.
26. Krishnamurthy R, Srinivasamurthy CA. Distribution of some available micronutrients in black and red soils of Karnataka. Mysore Journal of Agricultural Sciences. 2001; 39(1):57-63.
27. Kumar MB, Subbarayappa CT, Ramamurthy V. Distribution of Available (DTPA-extractable) Zinc and Iron and their Relationship with Some Soil Properties in Rice Soils of Chamarajanagar District, Karnataka, India. International Journal of Current Microbiology and Applied Sciences. 2017; 6(5):1423-1428.
28. Kumar M, Babel AL. Available micronutrient status and their relationship with soil properties of Jhunjhunu Tehsil, District Jhunjhunu, Rajasthan. India Journal of Agricultural Sciences. 2011; 3:20-31.
29. Lindsay WL, Norvell WA. Development of DTPA soil test for Zn, Fe, Mn and Cu. American Journal of Soil Science. 1978; 42:421-428.
30. Mandal LN, Mandal B. Zinc fractions in soils in relation to Zinc nutrition of lowland rice. Soil Science. 1986; 142:141-148.
31. Maret W. Zinc Biochemistry: From a Single Zinc Enzyme to a Key Element of Life. Advances in Nutrition. 2013; 4(1):82-91.
32. Mukesh J. Studies on Distribution and Forms of Zinc in Soils of Tonkkhurd Tehsil of Dewas District of Madhya Pradesh. Department of Soil Science and Agricultural Chemistry, Krishi Vishwa Vidyalaya College of Agriculture Indore (M.P), 2013.
33. Murthy ASP. Zinc fraction in wetland rice soils and their availability to rice. Soil Science. 1982; 133:150-154.
34. Page AL, Miller RH, Kenay DR. Methods of soil analysis, Part-2, Soil Science Society of America, 1982.
35. Pal AK, Das PR, Patnaik SK, Mandal B. Zinc fractions in some rice growing soils of Orissa. Journal of Indian Society of Soil Science. 1997; 45:734-738.
36. Pandit TK, Mookherjee S. Evaluation of soil fertility status in old alluvial zone of West Bengal. International Journal of Agricultural science and Research. 2016. ISSN (P):2250-2257.
37. Prasad R, Sakal R. Effect of soil properties on different chemical pools of Zinc in calcareous soils. Journal of Indian Society of Soil Science. 1988; 36:246-251.
38. Prashantha. Studies on different fractions of zinc and their relation with physico-chemical properties of soils under rice based cropping system in Davangere district of Karnataka. University of Agricultural Sciences, Bengaluru, 2011.
39. Ramzan S, Bhat AM, Kirmani NA, Rasool R. Fraction of zinc and their association with soil properties in soils of Kashmir Himalayas. International Invention Journal of Agriculture and Soil Science. 2014; 2(8):132-142.
40. Ray SK, Mukhopadhyay D. A study on physicochemical properties of soils under different Tea growing regions of West Bengal. International Journal of Agriculture Sciences. 2012; 4(8):325-329.
41. Saffari M, Yasrebi J, Karimian N, Shan XQ. Evaluation of three sequential extraction methods for fractionation of zinc in calcareous and acidic soils. Research Biological Science. 2009; 4:848-857.
42. Sankar DG, Murugappan V. Distribution of micronutrient cations in soils of Amaravathi river command area of Tamil Nadu. Madras Agricultural Journal. 1995; 19:590-593.
43. Sarkar AK, Deb DL. Zinc fractions in rice soils and their contribution to plant uptake. Journal of Indian Society of Soil Science. 1982; 30:63-69.
44. Sathyanarayana T, Biswas TD. Chemical and mineralogical studies of associated red and black soils. Mysore Journal Agricultural Science. 1970; 4:253-262.
45. Sharma BD, Aggarwal VK, Mukhopadhyay SS, Arora H. Micronutrient distribution and their association with soil properties in Entisols of Punjab. Journal Agricultural Science. 2002; 72:334-340.
46. Sharma SK, Lal F. Status of DTPA extractable zinc in soils of humid southern zone of Rajasthan. Journal of Indian Society of Soil Science. 1992; 40(2):393-394.
47. Singh MV, Abrol IP. Transformation and availability of zinc in alkali soils. Fertilizer News. 1986; 31(7):17-27.

48. Singh AK, Khan SK, Nongkynrih P. Transformation of zinc in wetland rice soils in relation to nutrition of rice crop. Journal of Indian Society of Soil Science. 1999; 47:248-253.
49. Singh JP, Karwassa SP, Singh M. Distribution and forms of copper, iron, manganese and zinc in calcareous soils of India. Soil Science. 1988; 146:359-366.
50. Singh SK, Rajeev K, Singh UK. Soil zinc fractions in a long term cropped and fertilized soils in an acid alfisol of Ranchi. Environ. Ecol. 2011; 29:198-201.
51. Singhal, Rattan RK. Soil Zinc fractions and their availability in some Inceptisols and Entisols. Journal of Indian Society of Soil Science. 1995; 43:80-83.
52. Soltania SM, Hanafi MM, Samsuri, Wahid, Syed MSK. Zinc fractionation of tropical paddy soils and their relationships with selected soil properties. Chemical Speciation & Bioavailability. 2015; 27(2):53-61.
53. Spalbar E, Mondal AK, Rai AP. Distribution of Zinc Fractions and Its Association with Soil Properties in Some Rice-Wheat Growing Soils of Jammu Region, India. International Journal of Current Microbiology and Applied Sciences. 2017; 6(4):711-721.
54. Subbiah BV, Asija GL. A rapid procedure for the estimation of available nitrogen in soils. Current Science. 1956; 25:259-260.
55. Sundararaj N, Nagaraju S, Venkataramu MN, Jagannatha MK. Design and analysis of field experiments. University of Agricultural Sciences, Bangalore, 1972.
56. Tehrani MM. Zinc mobility and its distribution among different pools in soil. Journal of Geophysical Research. 2005; 7:1056.
57. Tiwari JR, Mishra BB. Distribution of micronutrients in Tal land soils (Udic Chromusterts) of Bihar. Journal of Indian Society of Soil Science. 1990; 38:319-321.
58. Viets FG Jr. The chemistry and availability of micronutrients in soils. Journal of Agriculture and Food Chemistry 1962; 10:174 -178.
59. Walkley A, Black CA. An examination of digestion methods for determining soil organic matter and a proposed modification of the chromic acid titration method. Soil Science. 1934; 37:29-38.
60. Wijebandara DMD. Studies on distribution and transformation of soil zinc and response of rice to nutrients in traditional and system of rice intensification (SRI) methods of cultivation. Department of soil science and agricultural chemistry college of agriculture, Dharwad, 2007.
61. Wijebandara DMD, Dasog GS, Patil LR, Manjunath H. Zinc fractions and their relationships with soil properties in paddy-growing soils of northern dry and hill zones of Karnataka. Journal of Indian Society of Soil Science. 2011; 59:141-147.