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Characterization and delineation of micronutrient pools in some selected *Inceptisols* and *Alfisols* of West Bengal

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Abstract

The present study has been conducted to determine the cationic micronutrient (Zn, Cu, Fe, Mn) pools based on other factors towards plant availability in 20 selected soil series (10 series each from *Alfisols* and *Inceptisols*) of West Bengal. Apart from physicochemical characterization, the soils were sequentially extracted for different fractions such as the water-soluble and exchangeable (SE); organically bound (OB); manganese oxide–bound / occluded (MnOx), amorphous iron oxide-bound (Am_FeOx), crystalline oxide-bound (Cry_FeOx) fractions using sequential extraction process.

The percent predominance of the manganese fractions in the selected *Alfisols* and *Inceptisols* followed the order as MnOx > Am_FeOx > Cry_FeOx > OB > SE fractions while for copper, it followed the order as OB > Cry_FeOx > Am_FeOx > SE > MnOx fractions. The percent predominance of the iron fractions in the selected *Alfisols* and *Inceptisols* followed the order as Cry_FeOx > Am_FeOx > MnOx > OB > SE fractions while for zinc, it followed the order as Am_FeOx > Cry_FeOx > MnOx > OB > SE fractions.

The different fractions of Zn, Cu, Fe, Mn were then stepwise regressed with other fractions and soil physicochemical properties. The most phyto-available fraction i.e. soluble and exchangeable Mn, Cu, Fe and Zn was found to be mostly governed by clay content of soil and organically bound fractions of respective elements.

Keywords: Micronutrients, fractions, inceptisols, alfisols, regression

Introduction

Micronutrients are essential elements taken up by plants in minute quantities include iron (Fe), manganese (Mn), zinc (Zn), copper (Cu), molybdenum (Mo), nickel (Ni) boron (B) and chlorine (Cl). Out of the cationic micronutrients, iron (Fe), manganese (Mn), zinc (Zn) and copper (Cu) are the most important ones. Micronutrients can only exhibit their function when present in balanced proportion (Tavakoli *et al.*, 2014) [70].

Among these four elements, Fe and Mn are termed as redox element for having more than one stable oxidation state and therefore play important roles on oxidation and reduction processes, as electron transport in photosynthesis, respiration and other biochemical and physiological pathways (Millaleo *et al.*, 2010 ; Mousavi *et al.*, 2011) [21, 45]. Manganese has important role on activation of several enzymes involved in oxidation reactions, carboxylation, carbohydrates metabolism, phosphorus reactions and citric acid cycle. It plays an important role in chlorophyll production and also involved in cell division and plant growth (Marschner, 2011; Tavakoli *et al.*, 2014) [37, 70]. The importance of iron is an lies in its essentiality for many important enzymes, including cytochrome that is involved in electron transport chain, chlorophyll synthesis etc. (Eskandari, 2011; Yadegari, 2014) [11, 77]. The main functions of zinc lies in the tendency to make up tetragonal complexes with nitrogen, oxygen and sulfur, thus zinc have a catalytic, building and activating role in the enzymes (Mousavi *et al.*, 2013; Maleki *et al.*, 2014 [45, 34]. Zinc plays an important role in most of the enzymes like alcohol dehydrogenase carbonic anhydrase, superoxide dismutase, alkaline phosphatase, phosphatides lipase, carboxypeptidase, RNA polymerase, dehydrogenase and aldolase (Pandey *et al.*, 2002; Mousavi *et al.*, 2011) [52, 45]. Copper is involved in several enzyme systems, cell wall formation and electron transport and oxidation reactions (ASK Saskatchewan Agriculture, 2012) [4].

Generally micronutrients in soils have been partitioned into different forms (McLaren and Crawford, 1973) [40] or pools (Viets, 1962) [73].

These are soluble and exchangeable, organically bound, manganese oxide bound, amorphous iron oxide bound and crystalline iron oxide bound (Shuman, 1988; Shuman, 1991; Moreira *et al*., 2016) [61, 58, 44].

Soluble and exchangeable (SE) pool although represents only a small fraction of the total metal content in soil, contributes greatly towards plant availability (Shukla & Anshumali, 2018) [56]. Next to the SE fraction, micronutrients associated with soil organic matter *via* incorporation into organic molecules, exchange, chelation, or by specific and nonspecific adsorption have a considerable share in plant uptake (Shuman, 1991; Moreira *et al*., 2016) [61, 44]. Furthermore, micronutrient metals associated with iron and manganese oxides and hydrous oxides *via* adsorption, ion exchange, surface complex formations, incorporation into the crystal lattice and co-precipitation remain in a dynamic equilibrium with SE and OB fractions intimately affecting plant availability in soil system (Mandal and Mitra, 1982; Mandal and Mandal, 1987; Shuman, 1991) [36, 35, 61].

A critical assessment of the different soil orders of West Bengal reveal that *Alfisol* and *Inceptisol* covers more than 75% of the area (Singh *et al*., 2009) [66]. The area are highly fertile and agriculturally productive (www.matirkotha.net) prioritizing the necessity to study of the soils from this area. On the above foreground, the study was catered with the objective of determining cationic micronutrient pools based on other factors towards plant availability.

Materials and Methods

Site selection and sampling

The experimental soils were collected from 20 different NBSS & LUP identified soil series (10 soil series each from *Inceptisol* and *Alfisol*). The varying sites and their characteristics have been presented in Table-1.

Physicochemical characterization

The physico-chemical properties (0-15 cm) of the experimental soils from the 20 different soil series were analysed following standard methodologies as follows:-

Parameters	Methodologies	References
pH	Soil-water suspension (1:2.5)	Jackson, 1973 [24]
EC	Soil-water suspension (1:2.5)	Jackson, 1967 [23]
Clay content	Hydrometer method	Bouyoucos, 1962 [7]
Organic Carbon	Wet oxidation method	Walkley and Black, 1934 [74]
Available N	Hot alkaline permanganate	Subbiah and Asija, 1956 [68]
Available P	0.5 M $NaHCO_3$ (pH 8.5)	Olsen and Sommers, 1982 [50]
	0.03 N NH_4F + 0.025 N HCl (pH 3.5)	Bray and Kurtz, 1945 [8]
Available K	Neutral Normal ammonium acetate extraction	Knudsen, Peterson and Pratt, 1982 [28]
Calcium Carbonate (%)	Alkalimetric titration of acidified soil extract	Horváth *et al*., 2005 [21]
Available Zn, Mn, Cu, Fe	DTPA extraction (pH 7.3)	Lindsay & Norvell, 1978 [31]
Amorphous Fe, Al and Mn oxides	0.2 M acidified ammonium oxalate	McKeague and Day, 1966 [39]
Total Zn, Mn, Cu and Fe	HNO_3:$HClO_4$::10:4 (v/v) digestion	Jackson, 1967 [23]

Determination of different pools of manganese, copper, iron & zinc through fractionation of the experimental soils

The soils have been extracted sequentially to determine different pools of manganese, copper, iron & zinc by the standard methods as described Shuman (1985) [58], Miller *et al*. (1986) [43] and Phillips and Chappie (1995) [53] modified by Golui *et al*. (2017) [17]. For execution, 2 g soil was treated sequentially with the series of extractants mentioned. After addition of each extractant to the soil, taken in a conical flask, the soil-extractant mixture was shaken in a reciprocating shaker, immediately centrifuged for 10 minutes at 2000 rpm and the supernatant solution was decanted into another conical flask, while the remaining solid residue was subsequently treated for the next step of fractionation.

The different fractions thus obtained of cationic micronutrients Zn, Mn, Cu & Fe included water-soluble and exchangeable; organically bound; manganese oxide -bound/occluded, amorphous iron oxide-bound and crystalline oxide-bound. Apart from this, the residual fractions i.e. carbonate bound and other was determined by subtracting the sum of the above-mentioned fractions from the total content.

Steps	Fractions	Extractant	Soil: Solution	Conditions
1	Water-soluble and exchangeable	1 M $Ca(NO_3)_2^a$	1:20	Shaking for 2 hours
2	Organically bound	0.02 M HNO_3+ 30% H_2O_2 (pH 2.0) (vol/vol) + 3.2M NH_4OAc in 20% HNO_3 (vol/vol)^c	1:20	Shaking for 2.5 hours
3	Manganese oxide-bound/occluded	0.01 M $NH_2OH.HCl$ + 0.1 M HNO_3^b	1:20	Shaking for 30 minutes
4	Amorphous Fe oxide bound	0.2 M NH_4-oxalate + 0.2 M Oxalic acid^a	1:20	Shaking for 4 hours in the dark
5	Crystalline Fe oxide bound	0.2 M NH_4-oxalate + 0.2 M Oxalic acid + 0.1 M Ascorbic acid^a	1:20	Boiling on water bath stir occasionally for 30 minutes

a. Shuman (1985) [58], b. Miller *et al*. (1986) [43], c. Phillips and Chappie (1995) [53] modified by Golui *et al*. (2017) [17]

Table 1: Selection criteria and location coordinates of the sites under study

Block	Series	Taxonomic Unit	Textural class	Latitude	Longitude	Elevation
			Alfisol			
Hura	Hura	Typic Haplustalfs	Sandy Clay Loam	23.301˚ N	86.659˚ E	208 m AMSL
Bundwan	Shimaldanga	Typic Haplustalfs	Loam	22.876˚ N	86.504˚ E	219 m AMSL
Puncha	Bishpuria	Ultic Haplustalfs	Sandy Loam	23.158˚ N	86.650˚ E	180 m AMSL
Manbazar	Sindurpur	Lithic Rhodustalfs	Sandy Loam	23.398˚ N	86.459˚ E	249 m AMSL
Puncha	Uparbaid	Typic Endoaqualfs	Sandy Clay Loam	23.156˚ N	86.649˚ E	173 m AMSL

Goaltor	Kusmasuli	Rhodic Paleustalfs	Sandy Loam	22.697° N	87.183° E	65 m AMSL
Goaltor	Barakadra	Aquic Haplustalfs	Loam	22.702° N	87.291° E	44 m AMSL
Jhargram	Jhargram	Ultic Paleustalfs	Loam	22.452° N	86.992° E	84 m AMSL
Teltaka	Teltaka	Aeric Endoaqualfs	Silt Loam	22.753° N	87.317° E	52 m AMSL
Kharagpur	Ruisanda	Vertic Endoaqualfs	Clay Loam	22.354° N	87.253° E	43 m AMSL
Inceptisol						
Haringhata	Jaguli	Fluventic Eutrochrepts	Sandy Loam	22.947° N	88.539° E	16 m AMSL
Ranaghat	Ranaghat-I	Typic Ustrochrepts	Sandy Clay Loam	23.167° N	88.544° E	12 m AMSL
Ranaghat	Ranaghat-II	Aeric Haplaquepts	Clay	23.204° N	88.522° E	13 m AMSL
Tehatta	Tehatta	Aquic Ustifluvents	Clay Loam	23.505° N	88.555° E	22 m AMSL
Haringhata	Sirajanpara	Vertic Eutrochrepts	Clay Loam	22.953° N	88.525° E	18 m AMSL
Chakdaha	Maheshwarpur	Typic Haplustepts	Silty Clay Loam	23.033° N	88.549° E	17 m AMSL
Chakdaha	Pachpota	Aeric Haplustepts	Silty Loam	23.074° N	88.533° E	16 m AMSL
Chakdaha	Barabill	Typic Haplustepts	Clay	23.078° N	88.547° E	16 m AMSL
Haringhata	Laupala	Fluventic Eutrochrepts	Sandy Loam	22.965° N	88.547° E	11 m AMSL
Chakdaha	Kughachhi	Typic Haplustepts	Silty Clay	23.046° N	88.546° E	12 m AMSL

Statistical Interpretations

The necessary computations of descriptive statistics of physicochemical properties and cationic micronutrient fractions and stepwise regression between those were performed using *Microsoft Excel 2016* and *SPSS version 23.0* (SPSS, Inc., Chicago, IL, USA).

Results

Characterization of experimental soils

The physico-chemical characteristics of these experimental soil series have been illustrated in table- 2, 3 and elucidated below.

The selected series of *Alfisols* (table-2) are slightly acidic in reaction (pH 6.140 ± 0.501), non-saline in character (EC_e 0.119 ± 0.071 dSm^{-1}), low in oxidizable organic carbon status (4.913 ± 1.298 g kg^{-1}) and low in clay fractions (191.100 ± 83.901 g kg^{-1}). The selected soils are low in available (alkaline permanganate) nitrogen (181.994 ± 35.621 kg ha^{-1}), moderate in available (Bray and Kutz No 1 reagent extractable) phosphorus (17.614 ± 6.897 kg ha^{-1}) and moderate in available (NH_4OAc extractable) potassium (126.314 ± 34.899 kg ha^{-1}). The DTPA extractable micronutrients *viz.* Zn (1.209 ± 0.239 mg kg^{-1}), Cu (1.211 ± 0.339 mgkg^{-1}), Fe (44.426 ± 12.056 mg kg^{-1}) and Mn (43.162 ± 11.699 mg kg^{-1}) are more or less sufficient. The recoveries of amorphous Fe (7.132 ± 0.621 g kg^{-1}) and Mn-oxide are relatively higher (2.210 ± 0.919 g kg^{-1}). The Calcium carbonate content was found to be 44.102 ± 11.499 g kg^{-1}. Therefore, ten selected soil series under *Alfisols* order under study varied significantly.

The selected series of *Inceptisols* (table-3) are neutral in reaction (pH 7.121 ± 0.209), non-saline in character (EC_e 0.289 ± 0.081 dSm^{-1}), moderate to high in oxidisable organic carbon status (6.928 ± 1.059 g kg^{-1}) and clay fractions (346.210 ± 119.899 g kg^{-1}). The selected soils are low to moderate in available (alkaline permanganate) nitrogen (261.478 ± 27.903 kg ha^{-1}), high in available ($NaHCO_3$ extractable) phosphorus (42.199 ± 12.102 kgha^{-1}) and moderate in available (NH_4OAc extractable) potassium (225.891 ± 32.995 kg ha^{-1}). The DTPA extractable micronutrients *viz.* Zn (1.611 ± 0.440 mg kg^{-1}), Cu (1.279 ± 0.398 mgkg^{-1}), Fe (12.331 ± 2.504 mg kg^{-1}) and Mn (11.609 ± 2.169 mg kg^{-1}) are more or less sufficient. The recoveries of amorphous Fe (6.070 ± 1.258 g kg^{-1}) was higher while that of Mn-oxide (0.850 ± 0.271 g kg^{-1}) are relatively lower. The Calcium carbonate content was found to be 50.798 ± 13.392 g kg^{-1}. A significant variation among the ten selected soil series under *Inceptisols* was observed.

Recoveries of fractions of manganese, copper, iron & zinc of initial soils through sequential extraction

Following the standard protocols, the experimental soils were sequentially extracted for obtaining various pools of the micronutrients.

The water soluble and exchangeable (SE), organically bound (OB) manganese oxide-bound/occluded (MnOx), amorphous iron oxide-bound (Am_FeOx), crystalline iron oxide-bound (Cry_FeOx) and residual fractions of manganese, copper, iron & zinc in *Alfisols* (Table-4) were observed to be in the ranges of 3.37-9.56 (5.94) mg kg^{-1}, 16.88-34.13 (22.19) mg kg^{-1}, 80.33-149.41 (113.55) mg kg^{-1}, 32.35-77.85 (52.58) mg kg^{-1}, 21.85-46.53 (36.01) mg kg^{-1} and 37.21-90.4 (54.46) mg kg^{-1}; 0.315-1.273 (0.80) mg kg^{-1}, 7.535- 14.204 (10.36) mg kg^{-1}, 0.666 - 0.315 (0.50) mg kg^{-1}, 5.365-9.208 (6.71) mg kg^{-1}, 6.322-9.796 (7.51) mg kg^{-1} and 9.678-14.057 (11.49) mg kg^{-1}; 159.48-487.63 (364.27) mg kg^{-1}, 850.57 - 2030.1 (1451.14) mg kg^{-1}, 1709.37 - 4255.68 (3050.26) mg kg^{-1}, 2094.26 - 4957.88 (3786) mg kg^{-1}, 2466.65-5496.92 (4075.85) mg kg^{-1} and 2796.24 - 6279.98 (4732.05) mg kg^{-1}; 0.5-1.8 (1.04) mg kg^{-1}, 2.1-5.54 (3.86) mg kg^{-1}, 5.79-11.1 (8.66) mg kg^{-1}, 7.4-18.71 (12.39) mg kg^{-1}, 6.17-13.86 (10.10) mg kg^{-1} and 7.4-18.13 (14.27) mg kg^{-1} respectively.

Similarly, the fractions of these cationic micronutrients i.e. water soluble and exchangeable (SE), organically bound (OB) manganese oxide-bound/occluded (MnOx), amorphous iron oxide-bound (Am_FeOx), crystalline iron oxide-bound (Cry_FeOx) and residual among the selected *Inceptisols* (Tabel-5) ranged from 4.34-12.38 (8.90) mg kg^{-1}, 39.44-65.67 (53.81) mg kg^{-1}, 90.62- 147.16 (122.45) mg kg^{-1}, 42.05-77.15 (60.98) mg kg^{-1}, 54.02-84.46 (69.11) mg kg^{-1} and 84.83-146.24 (115.28) mg kg^{-1}; 0.46-1.78 (1.06) mg kg^{-1}, 14.48-23.23 (18.39) mg kg^{-1}, 0.31-0.69 (0.48) mg kg^{-1}, 5.38- 8.54 (6.51) mg kg^{-1}, 5.22-10.25 (6.84) mg kg^{-1} and 13.41-25.29 (16.82) mg kg^{-1}; 306.02-1368.7 (789.14) mg kg^{-1}, 2986.56 - 6315.62 (4465.42) mg kg^{-1}, 3742.44- 6318.97 (5010.94) mg kg^{-1}, 5295.33-9423.31 (6830.45) mg kg^{-1}, 7013.38-11077.4 (8718.41) mg kg^{-1} and 9282.42-16841.66 (11968.14) mg kg^{-1}; 0.64-2.9 (1.53) mg kg^{-1}, 4.46-11.93 (8.78) mg kg^{-1}, 5.27-13.56 (9.42) mg kg^{-1}, 11.35-27.12 (19.01) mg kg^{-1}, 5.27-16.27 (9.90) mg kg^{-1} and 13.46-38.61 (23.37) mg kg^{-1} respectively.

The percent predominance of the manganese fractions in the selected *Alfisols* and *Inceptisols* followed the order as MnOx

> Am_FeOx > Cry_FeOx > OB > SE fractions while for copper, it followed the order as OB > Cry_FeOx > Am_FeOx > SE > MnOx fractions. The percent predominance of the iron fractions in the selected *Alfisols* and *Inceptisols* followed the order as Cry_FeOx > Am_FeOx > MnOx > OB > SE fractions while for zinc, it followed the order as Am_FeOx > Cry_FeOx > MnOx > OB > SE fractions. The mean values of different fractions of Mn, Cu, Fe and Zn as percentage of the total is represented as pie diagrams in the figures.

Micronutrient fractions and soil physico-chemical properties: Relationship and Interrelationship

The characterization of selected micronutrients (Cu, Mn, Zn and Fe) in soil and the relative abundance of different fractions are largely governed by their relationship with soil physico-chemical properties and the interrelationship of the existing fractions as well. In the ensuing section, we tried to elucidate and understand such relationships and impacts thereof on soil micronutrients status.

Table 2: Physico-chemical parameters of selected *Alfisols* under study

Soil series	pH	EC (dSm^{-1})	Clay (g kg^{-1})	Org. C (g kg^{-1})	Av_N (kg ha^{-1})	Av_P (kg ha^{-1})	Av_K (kg ha^{-1})	Am-Fe (g kg^{-1})	$CaCO_3$ (g kg^{-1})	Mn-O (g kg^{-1})	Av_Zn (mg kg^{-1})	Av_Mn (mg kg^{-1})	Av_Cu (mg kg^{-1})	Av_Fe (mg kg^{-1})
Hura	5.910	0.210	364.000	5.700	148.600	12.544	112.200	6.250	44.300	0.940	1.131	30.050	1.546	30.450
Shimaldanga	6.570	0.103	192.000	6.600	178.360	10.752	119.800	6.980	41.300	3.840	0.950	51.230	0.932	52.120
Bishpuria	5.730	0.230	172.000	4.200	182.320	12.992	125.600	7.940	37.700	0.980	1.200	55.210	1.096	44.120
Sindurpur	6.240	0.184	121.000	4.500	140.480	13.888	122.100	7.210	32.800	2.820	1.286	31.200	1.187	28.650
Uparbaid	6.840	0.098	204.000	5.400	142.210	15.232	109.200	7.520	64.900	1.720	1.742	30.120	2.004	34.120
Kusmasuli	6.750	0.074	168.000	3.600	182.670	30.016	222.800	6.510	44.900	3.210	0.963	48.230	0.874	65.020
Barakadra	6.120	0.054	92.000	3.900	187.420	26.432	99.800	6.940	52.400	2.010	1.183	60.100	1.030	53.560
Jhargram	5.220	0.116	124.000	3.900	185.320	14.784	108.700	6.540	58.800	2.460	1.341	40.100	1.304	39.510
Teltaka	6.080	0.069	162.000	4.200	214.880	25.536	126.400	8.160	32.700	1.850	1.370	32.240	0.963	55.370
Ruisanda	5.870	0.057	302.000	7.500	258.340	13.888	116.700	7.240	31.100	2.250	0.968	53.110	1.124	40.250
Mean	6.140	0.119	191.100	4.913	181.994	17.614	126.314	7.132	44.102	2.210	1.209	43.162	1.211	44.426
SD	0.501	0.071	83.901	1.298	35.621	6.897	34.899	0.621	11.499	0.919	0.239	11.699	0.339	12.056

Table 3: Physico-chemical parameters of selected *Inceptisols* under study

Soil series	pH	EC (dSm^{-1})	Clay (g kg^{-1})	Org. C (g kg^{-1})	Av_N (kg ha^{-1})	Av_P (kg ha^{-1})	Av_K (kg ha^{-1})	Am-Fe (g kg^{-1})	$CaCO_3$ (g kg^{-1})	Mn-O (g kg^{-1})	Av_Zn (mg kg^{-1})	Av_Mn (mg kg^{-1})	Av_Cu (mg kg^{-1})	Av_Fe (mg kg^{-1})
Jaguli	7.120	0.245	144.000	6.600	265.400	37.632	229.800	4.560	42.800	0.660	2.486	12.300	1.406	10.450
Ranaghat-I	7.240	0.202	340.000	8.400	286.480	60.032	294.600	8.460	65.700	1.540	1.660	10.120	1.548	12.310
Ranaghat-II	7.050	0.282	525.000	7.500	274.300	32.256	212.300	6.420	50.800	0.990	1.960	9.560	0.993	14.210
Tehatta	6.780	0.242	324.000	7.800	260.740	52.416	204.600	5.240	51.400	0.840	1.453	11.320	0.973	15.720
Sirajanpara	7.190	0.223	388.000	6.300	288.400	28.672	198.200	6.650	32.400	0.820	1.476	15.420	0.883	13.420
Maheshwarpur	6.870	0.372	364.000	7.200	214.420	34.944	215.600	4.950	51.100	0.780	1.473	10.050	1.682	11.210
Pachpota	7.550	0.272	279.000	6.600	250.460	43.456	232.400	7.580	67.600	0.750	0.934	14.120	1.238	9.120
Barabill	7.140	0.367	422.000	4.500	217.500	50.176	206.800	5.240	28.300	0.820	1.427	13.250	2.100	9.960
Laupala	7.020	0.258	182.000	7.500	292.340	25.984	192.600	6.420	53.400	0.620	1.243	11.450	0.902	16.340
Kughachhi	7.210	0.447	484.000	6.900	244.620	56.448	272.400	5.140	64.700	0.640	1.976	8.530	1.089	10.540
Mean	7.121	0.289	346.210	6.928	261.478	42.199	225.891	6.070	50.798	0.850	1.611	11.609	1.279	12.331
SD	0.209	0.081	119.899	1.059	27.903	12.102	32.995	1.258	13.392	0.271	0.440	2.169	0.398	2.504

Table 4: Initial fractions of micronutrients for selected *Alfisols* (mg Kg^{-1})

Soil series		Hura	Shimaldanga	Bishpuria	Sindurpur	Uparbaid	Kusmasuli	Barakadra	Jhargram	Teltaka	Ruisanda	Mean
Manganese	SE	6.43	7.78	7.75	3.37	5.63	6.94	3.40	3.96	4.54	9.56	5.94
	OB	17.14	31.13	26.42	17.55	17.31	19.55	24.59	17.16	16.88	34.13	22.19
	MnOx	80.33	137.82	132.09	93.35	83.29	129.91	149.41	106.38	86.11	136.85	113.55
	Am_FeOx	32.35	59.02	77.85	40.94	46.08	54.87	63.93	43.82	44.14	62.79	52.58
	Cry_FeOx	33.20	41.51	38.40	28.34	26.83	43.83	46.53	38.27	21.85	41.29	36.01
	Residual	44.77	47.02	69.75	41.39	37.21	60.23	90.40	54.38	42.84	56.65	54.46
	Total	214.21	324.29	352.25	224.95	216.35	315.32	378.26	263.96	216.36	341.26	284.72
Copper	SE	1.27	0.80	0.77	0.54	1.27	0.66	0.31	0.57	0.77	1.06	0.80
	OB	12.25	10.00	9.48	10.05	14.20	7.54	9.16	9.65	9.95	11.36	10.36
	MnOx	0.63	0.67	0.53	0.65	0.44	0.57	0.31	0.45	0.33	0.38	0.50
	Am_FeOx	6.55	5.50	7.02	6.54	9.21	5.36	6.30	6.60	7.01	7.00	6.71
	Cry_FeOx	9.29	6.66	6.32	7.23	9.80	6.33	7.00	8.31	6.64	7.57	7.51
	Residual	12.25	9.70	10.99	11.13	14.06	9.68	11.89	12.56	12.17	10.49	11.49
	Total	42.23	33.32	35.12	36.14	48.98	30.14	34.98	38.14	36.87	37.86	37.38
Iron	SE	339.61	482.40	422.73	159.48	363.07	487.63	189.05	254.37	462.74	481.60	364.27
	OB	1018.83	2030.10	1517.99	850.57	1172.99	1551.55	1575.45	1271.85	1784.84	1737.20	1451.14
	MnOx	1709.37	4060.20	2728.53	2009.47	2359.95	4255.68	3634.04	2984.61	3767.99	2992.80	3050.26
	Am_FeOx	2094.26	3919.50	4419.45	2349.69	3183.84	4831.97	4621.32	3612.05	4957.88	3870.00	3786.00
	Cry_FeOx	2886.68	4723.50	4131.23	2466.65	3281.59	5496.92	4810.37	4120.79	4781.60	4059.20	4075.85
	Residual	3271.57	4884.30	5995.08	2796.24	3602.76	5541.25	6175.76	4714.32	6279.98	4059.20	4732.05
	Total	11320.30	20100.00	19215.00	10632.10	13964.20	22165.00	21006.00	16958.00	22035.00	17200.00	17459.56
Zinc	SE	1.63	0.74	1.00	0.88	1.80	0.75	0.50	0.92	1.31	0.90	1.04
	OB	4.35	2.96	3.39	4.56	5.54	2.10	3.59	4.00	4.86	3.22	3.86

	MnOx	8.15	6.17	6.79	11.10	11.09	6.44	9.38	11.07	10.60	5.79	8.66
	Am_FeOx	11.41	7.40	12.67	14.02	18.71	7.80	13.24	14.14	16.83	7.72	12.39
	Cry_FeOx	11.95	6.17	8.14	11.68	13.86	7.12	11.04	13.40	11.22	6.43	10.10
	Residual	16.84	7.40	13.26	16.18	18.30	9.70	17.44	17.96	17.52	8.11	14.27
	Total	54.33	30.83	45.24	58.41	69.31	33.92	55.18	61.49	62.34	32.17	50.32

Table 5: Initial fractions of micronutrients for selected *Inceptisols* (mg Kg^{-1})

Soil series		Jaguli	Ranaghat-I	Ranaghat-II	Tehatta	Sirajanpara	Maheshwarpur	Pachpota	Barabill	Laupala	Kughachhi	Mean
Manganese	SE	4.34	8.00	12.38	9.06	12.26	8.36	8.90	12.04	4.54	9.13	8.90
	OB	54.54	61.62	48.81	65.67	57.74	50.97	55.89	48.15	55.30	39.44	53.81
	MnOx	132.73	121.64	107.45	129.08	147.16	112.30	138.98	131.02	113.49	90.62	122.45
	Am_FeOx	60.33	70.02	52.81	60.69	73.07	54.96	77.15	59.26	59.43	42.05	60.98
	Cry_FeOx	84.46	54.02	55.36	76.09	78.18	67.30	75.67	80.09	63.55	56.39	69.11
	Residual	146.24	84.83	87.42	112.32	142.56	104.34	137.99	132.41	116.38	88.34	115.28
	Total	482.65	400.12	364.23	452.91	510.96	398.24	494.58	462.97	412.68	325.96	430.53
Copper	SE	0.46	1.06	1.47	0.85	0.96	1.28	0.96	1.78	0.46	1.28	1.06
	OB	18.46	21.30	16.65	16.65	14.48	23.23	19.04	21.86	16.20	16.00	18.39
	MnOx	0.47	0.69	0.48	0.42	0.31	0.56	0.45	0.60	0.38	0.42	0.48
	Am_FeOx	6.08	7.99	5.62	5.38	5.42	7.03	7.50	8.54	5.79	5.73	6.51
	Cry_FeOx	7.67	5.86	5.62	5.98	5.22	8.56	6.91	10.25	5.45	6.88	6.84
	Residual	17.98	16.34	13.41	13.41	13.73	20.47	18.32	25.29	13.67	15.53	16.82
	Total	51.12	53.24	43.25	42.69	40.12	61.12	53.19	68.32	41.96	45.84	50.09
Iron	SE	306.02	780.12	1368.70	902.48	946.82	735.13	530.42	786.73	551.36	983.61	789.14
	OB	3774.22	5070.78	5072.26	5640.50	4142.36	4235.73	3270.95	2986.56	6315.62	4145.22	4465.42
	MnOx	4114.24	6318.97	5716.35	6227.11	5365.34	4655.80	3742.44	4084.97	5914.63	3969.58	5010.94
	Am_FeOx	5746.34	7801.20	7246.08	7941.82	7298.44	5775.99	5628.39	5295.33	9423.31	6147.58	6830.45
	Cry_FeOx	8330.49	7996.23	9057.60	10468.77	8758.12	8366.43	7013.38	7473.97	11077.40	8641.73	8718.41
	Residual	11730.69	11038.70	11795.01	13943.32	12939.93	11236.93	9282.42	9631.44	16841.66	11241.28	11968.14
	Total	34002.00	39006.00	40256.00	45124.00	39451.00	35006.00	29468.00	30259.00	50124.00	35129.00	37782.50
Zinc	SE	0.98	1.35	2.90	1.30	1.59	1.37	0.73	1.77	0.64	2.68	1.53
	OB	11.93	10.09	11.07	9.07	7.29	8.17	4.46	6.81	7.59	11.31	8.78
	MnOx	13.56	10.09	11.92	8.42	8.61	8.49	5.27	8.85	7.00	11.98	9.42
	Am_FeOx	27.12	20.18	23.00	16.84	17.89	16.99	11.35	17.03	15.76	23.96	19.01
	Cry_FeOx	16.27	7.40	11.07	9.07	8.61	9.15	5.27	10.22	7.59	14.38	9.90
	Residual	38.61	18.16	25.21	20.08	22.26	21.17	13.46	23.43	19.79	31.53	23.37
	Total	108.46	67.25	85.17	64.77	66.25	65.34	40.53	68.11	58.37	95.84	72.01

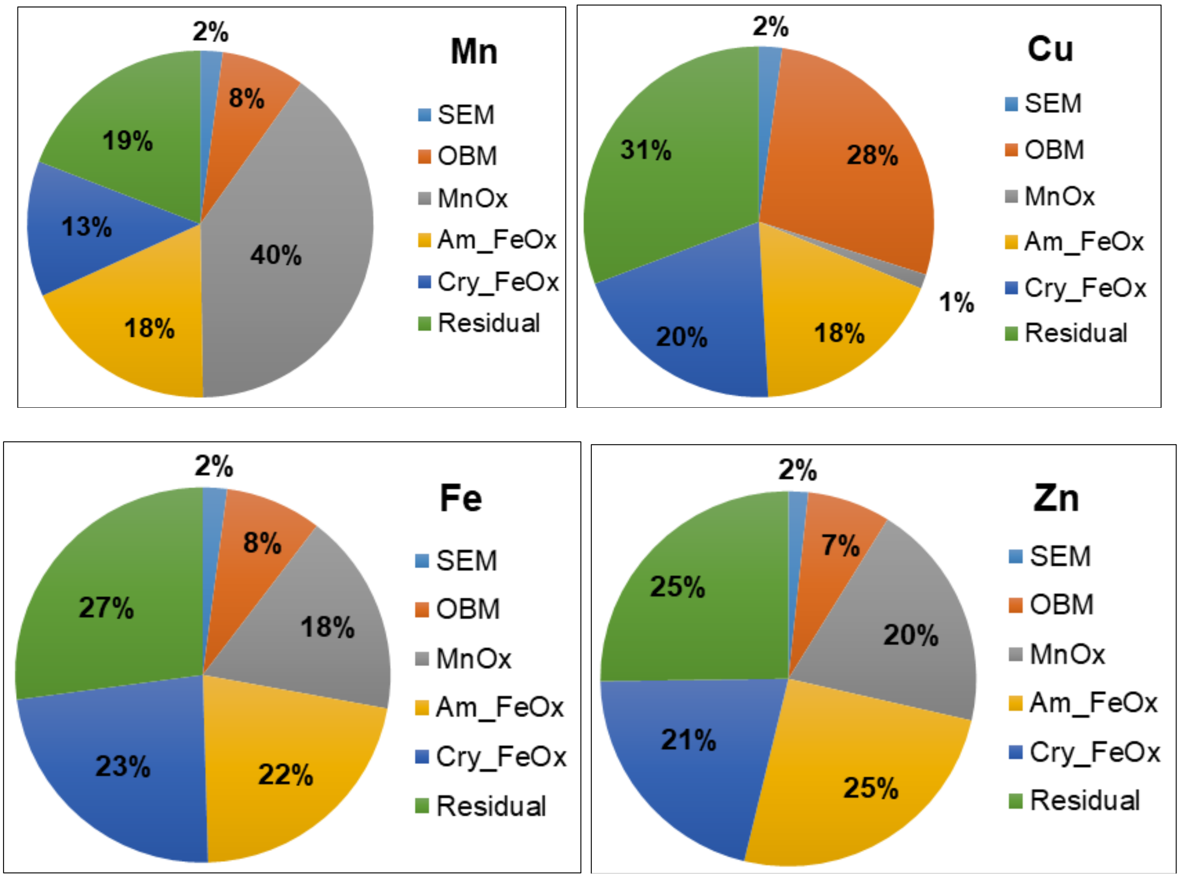


Fig 2: Initial fractions of manganese, copper, zinc and iron as % of the total in the selected *Alfisols*

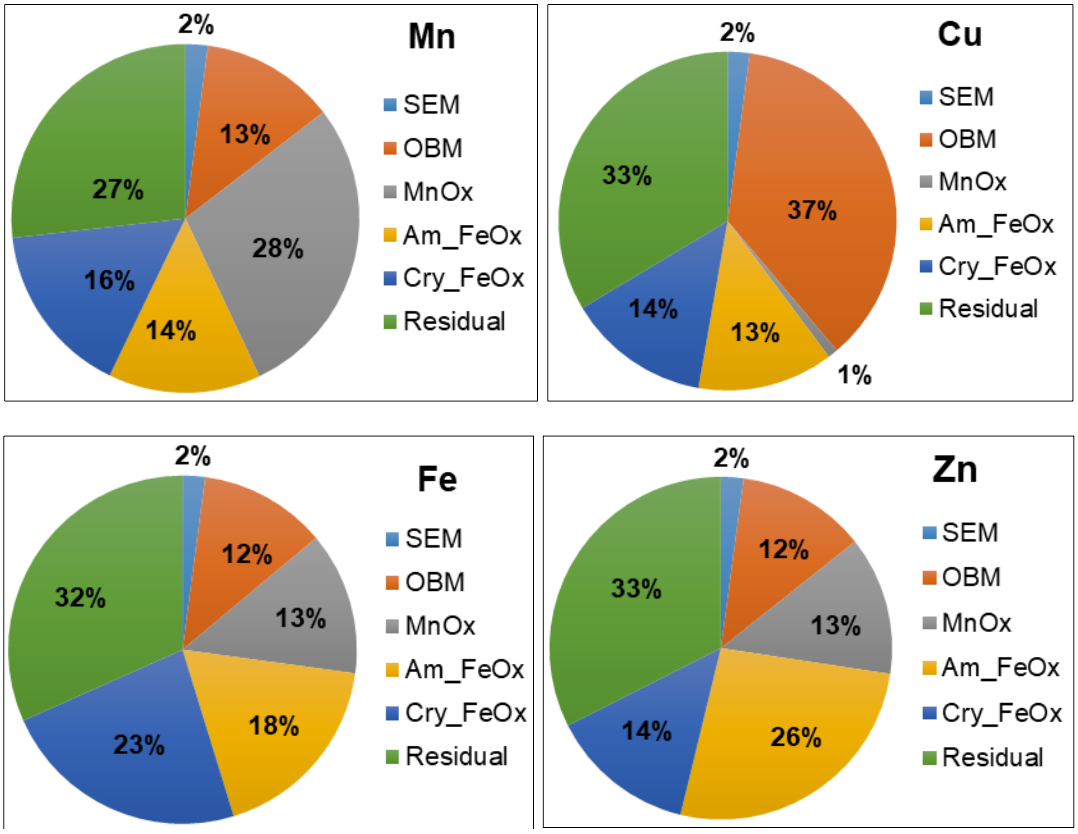


Fig 3: Initial fractions of manganese, copper, zinc and iron as % of the total in the selected *Inceptisol*

Manganese

Total and fractions of soil manganese were statistically regressed against soil physico-chemical properties. The inter relationship between Mn fractions have also been computed to assess the source-sink movement of soil Mn (Tables 6-7).

Table 6: Relationship and Interrelationship of Mn fractions in *Alfisol*

	R^2	Adj-R^2	$SE_{est.}$
Between fractions			
SE			
Y= 13.841 + 0.183 OB*	0. 863	0.744	0.255
OB			
Y= 31.831 -0.178 Residual*	0.913	0.833	0.177
MnOx			
Y= 143.434 + 2.210 Am_FeOx*	0.915	0.837	0.956
Am_FeOx			
Y= 101.442 + 0.379 MnOx*	0.920	0.842	0.984
Cry_FeOx			
Y= 256.036 -0.651 Am_FeOx*	0.921	0.842	0.968
Residual			
Y= 132.25 – 2.735 MnOx**	0.841	0.809	0.662
With physicochemical properties			
SE			
Y= 0.659 + 1.319 Clay*	0.677	0.458	1.981
OB			
Y= 22.122 + 3.1270 OC* - 1.567 Am_Fe*	0.891	0.881	1.128
Y= 10.816 + 5.428 OC *	0.780	0.760	1.516
MnOx			
Y= 10.969 + 2.224 MnO *	0.783	0.767	5.318
Am_FeOx			
Y= 54.660 + 8.891 Am_Fe*	0.788	0.729	7.087
Cry_FeOx			
Y= 48.14 - 8.504 MnO* -5.514 Am_Fe*	0.864	0.746	3.657
Y=68.701- 5.507 MnO**	0.763	0.712	9.654
Residual			
Y= 83.139 - 9.642 Am_Fe**- 4.057 OC*	0.952	0.907	8.443
Y= 67.337- 9.425 Am_Fe *	0.863	0.744	13.112

The changes in soluble and exchangeable manganese (SE-Mn) are mostly governed by clay content of soil (45.8 % in *Alfisols* and 72.6% in *Inceptisols*) and organically bound manganese (74.4% in *Alfisols* and 78.4% in *Inceptisols*). Organically bound manganese (OB-Mn) content is mostly governed by oxidizable organic carbon and amorphous iron oxide content in *Alfisols* (88.1%) while in *Inceptisols*, oxidizable organic carbon largely controls the variation of OB-Mn (76.4%) Among Mn fractions, residual manganese was the major contributory (dictates 83.3% variation of OB-Mn in *Alfisol* and 81.2% in *Inceptisol*). Variations in MnOx-Mn are mostly governed by manganese oxide content of soil (76.7% in *Alfisols*) and manganese oxide and soil clay content (93.9% in *Inceptisols*) and amorphous iron oxide bound Mn fraction (83.7% in *Alfisols* and 85.1% in *Inceptisols*). Amorphous iron oxide bound fraction is largely impacted by changes in amorphous iron oxide content in *Alfisols* (72.9%) and amorphous iron oxide content and soil clay content of *Inceptisols* (80.4%). Manganese oxide bound Mn fractions was observed to dictate variations in amorphous iron oxide bound Mn (84.2% in *Alfisols* and 82.5% in *Inceptisols*). Crystalline iron oxide bound fraction is mostly affected by variations in amorphous iron oxide and manganese oxide content in *Alfisols* (74.6%) and by variations in manganese oxide in *Inceptisols* (60.3%). Cry_FeOx-Mn was observed further to be largely governed by changes in amorphous iron oxide bound fraction (84.2% in *Alfisols* and 85.2% in *Inceptisols*).

Table 7: Relationship and Interrelationship of Mn fractions in *Inceptisols*

	R^2	Adj-R^2	SEest.
Between fractions			
SE			
Y= 19.541 + 0.245 OB*	0. 841	0.784	0.284
OB			
Y= 48.245 - 0.289 Residual*	0.982	0.812	0.198
MnOx			
Y= 123.497 + 4.610 Am_FeOx*	0.901	0.851	0.932
Am_FeOx			
Y= 124.56 + 0.299 MnOx*	0.891	0.825	0.954
Cry_FeOx			
Y= 248.036 - 0.639 Am_FeOx*	0.903	0.854	0.923
Residual			
Y= 99.453 – 1.735 Am_FeOx **	0.823	0.796	0.624
With physicochemical properties			
SE			
Y= 2.318 + 0.024 Clay*	0.852	0.726	1.926
OB			
Y= 60.509 + 8.814 OC*	0.864	0.746	4.110
MnOx			
Y= 180.813 + 29.582 MnO** - 5.004 Clay*	0.927	0.939	0.270
Y= 0.44+ 34.583 MnO**	0.824	0.786	0.556
Am_FeOx			
Y= 3.355 + 3.45 Am_Fe * - 0.023 clay*	0.835	0.804	4.452
Y= 2.094+3.910 Am_Fe *	0.767	0.589	7.525
Cry_FeOx			
Y= 39.565 - 4.168 MnO*	0.777	0.603	6.385
Residual			
Y= 28.062 - 4.991 Am_Fe*	0.896	0.803	7.781

Residual Mn is mostly governed by variations in amorphous iron and oxidizable organic carbon (90.7% in *Alfisols*) and amorphous iron oxide content (80.3% in *Inceptisols*). Changes in residual Mn are mainly dictated by manganese oxide bound fraction (80.9% in *Alfisol*) and amorphous iron oxide bound fraction (79.6% in *Inceptisols*).

Copper

Total and fractions of soil copper were statistically regressed against soil physico-chemical properties. The inter relationship between Cu fractions have also been computed to assess the source-sink movement of soil Cu (Table 8-9).

The changes in soluble and exchangeable copper are mostly governed by clay content and oxidisable organic carbon of soil (88.8% in *Alfisols* and 89.6% in *Inceptisols*) while clay content was the most important parameter in both *Inceptisol* (70.6%) and *Alfisol* (69.4%). Soluble and exchangeable copper was observed to be mostly impacted by changes in organically bound copper (56.8% in *Alfisols* and 57% in *Inceptisols*)

Table 8: Relationship and Interrelationship of Cu fractions in *Alfisol*

	R^2	Adj-R^2	SEest.
Between fractions			
SE			
Y= - 0.042 + 0.159 OB*	0.733	0.568	0.091
OB			
Y= 26.035 -1.016 Residual** -6.733 MnOx*	0.924	0.907	0.047
Y= 25.568 -1.274 Residual**	0.884	0.782	0.119
MnOx			

Y= 0.01 + 0.089 Am_FeOx**	0.986	0.965	0.124
Am_FeOx			
Y= - 0.018 + 13.768 MnOx*	0.935	0.916	0.049
Cry_FeOx			
Y= 10.580 - 0.692 Am_FeOx*	0.973	0.949	0.003
Residual			
Y= 25.024 – 0.95 MnOx** -6.125 Am_FeOx*	0.988	0.976	0.046
Y= 19.337 – 0.707 MnOx**	0.949	0.901	0.089
With physicochemical properties			
SE			
Y= - 0.278 + 0.024 Clay* + 0.0119 OC*	0.926	0.888	0.052
Y= 0.1+ 0.038 Clay **	0.716	0.694	0.087
OB			
Y= -1.462 + 3.899 OC** - 0.489 Am_Fe*	0.938	0.920	0.468
Y= 2.104 + 3.899 OC**	0.780	0.752	0.823
MnOx			
Y=0.546 + 0.089 MnO*	0.652	0.589	0.091
Am_FeOx			
Y= - 0.315 + 0.681 Am_Fe** -1.514 MnO*	0.958	0.946	0.303
Y= 0.047 + 0.651 Am_Fe*	0.756	0.726	0.681
Cry_FeOx			
Y= 6.408 - 0.448 Am_Fe*	0.940	0.923	0.312
Residual			
Y= 8.917 - 1.992 MnO*	0.778	0.750	0.775

Organically bound copper (OB-Cu) content is mostly governed by oxidizable organic carbon and amorphous iron oxide content in *Alfisols* (92%) while in *Inceptisols*, oxidizable organic carbon largely controls the variation of OB-Cu (78.7%) Among Cu fractions, residual and manganese oxide-bound copper were the major contributories (dictates 90.7% variation of OB-Cu in *Alfisol* and 91.7% in *Inceptisol*). Variations in MnOx-Cu are mostly governed by manganese oxide content of soil (58.9% in *Alfisols* and 65.5% in *Inceptisols*) and amorphous iron oxide bound Cu fraction (96.5% in *Alfisols* and 95.3% in *Inceptisols*). Amorphous iron oxide bound fraction is largely impacted by changes in amorphous iron oxide and manganese oxide content of *Alfisols* (94.6%) and amorphous iron oxide content and oxidizable organic content of *Inceptisols* (83.3%). Manganese oxide bound Cu fractions was observed to dictate variations in amorphous iron oxide bound Cu (91.6% in *Alfisols* and 91.3% in *Inceptisols*).

Crystalline iron oxide bound fraction is mostly affected by variations in amorphous iron oxide content of *Alfisols* (92.3%) and by variations in amorphous iron oxide and oxidisable organic carbon of *Inceptisols* (97.5%). Cry_FeOx-Cu was observed further to be largely governed by changes in amorphous iron oxide bound fraction (94.9% in *Alfisols* and 89.4% in *Inceptisols*). Residual Cu is mostly governed by variations in manganese oxide (75% in *Alfisols* and 80.3% in *Inceptisols*). Soil organic carbon, further, emerged as another important contributor to changes in residual Cu in *Inceptisols*. Changes in residual Cu is mainly dictated by amorphous iron oxide bound fraction (97.6% in *Alfisols* and 92.5% in *Inceptisols*).

Table 9: Relationship and Interrelationship of Cu fractions in *Inceptisols*

	R^2	Adj-R^2	SEest.
Between fractions			
SE			
Y= - 0.049 + 0.172 OB*	0.738	0.570	0.012
OB			
Y= 32.035 - 2.019 Residual** - 8.635 MnOx*	0.934	0.917	0.048
Y= 29.547 – 1.547 Residual**	0.881	0.795	0.169
MnOx			
Y= 0.01 + 0.079 Am_FeOx**	0.986	0.953	0.006
Am_FeOx			
Y= - 0.018 + 13.968 MnOx*	0.935	0.913	0.049
Cry_FeOx			
Y= 10.580 - 0.492 Am_FeOx*	0.973	0.949	0.003
Residual			
Y= 25.024 – 0.95 Am_FeOx** - 6.125MnOx*	0.988	0.925	0.046
Y= 19.337 – 0.707 Am_FeOx*	0.949	0.901	0.089
With physicochemical properties			
SE			
Y= - 0.292 + 0.014 Clay** + 0.251 OC*	0.917	0.896	0.043
Y= 0.018 + 0.001 Clay**	0.738	0.706	0.113
OB			
Y= 0.66 + 0.968 OC*	0.811	0.787	1.208
MnOx			
Y=0.54+ 0.247 MnO*	0.670	0.655	0.026

Am_FeOx			
Y= 0.082 + 4.705 Am_Fe* - 0.369 OC*	0.87	0.833	0.483
Y= 2.497 + 4.152 Am_Fe*	0.718	0.683	0.666
Cry_FeOx			
Y= 8.184 - 1.686 Am_Fe** -0.02 OC*	0.981	0.975	0.234
Y=10.571- 5.682 Am_Fe*	0.795	0.770	0.712
Residual			
Y= 9.038 - 4.193 MnO*- 1.536 OC*	0.902	0.890	1.384
Y= 14.268 – 5.478 MnO*	0.845	0.803	2.365

Iron

Total and fractions of soil iron were statistically regressed against soil physico-chemical properties. The inter relationship between Fe fractions have also been computed to assess the source-sink movement of soil Fe (Table 10-11).

The changes in soluble and exchangeable iron (SE-Fe) are mostly governed by clay content and soil pH in *Alfisols* (86.7%) and *Inceptisols* (97.1%) while clay content was the most important parameter in *Inceptisol* (81.4%) and *Alfisol* (68.4%). Soluble and exchangeable iron was observed to be mostly impacted by changes in organically bound iron (46.6% in *Alfisols* and 47.4% in *Inceptisols*).

The changes in soluble and exchangeable iron (SE-Fe) are mostly governed by clay content and soil pH in *Alfisols* (86.7%) and *Inceptisols* (97.1%) while clay content was the most important parameter in *Inceptisol* (81.4%) and *Alfisol* (68.4%). Soluble and exchangeable iron was observed to be mostly impacted by changes in organically bound iron (46.6% in *Alfisols* and 47.4% in *Inceptisols*).

Table 10: Relationship and Interrelationship of Fe fractions in *Alfisols*

	R^2	Adj-R^2	SEest.
Between fractions			
SE			
Y= 31.667 + 0.260 OB*	0.683	0.466	116.67
OB			
Y= 408.751 - 0.363 MnOx**	0.831	0.690	233.16
MnOx			
Y= -536.632 + 0.975 Cry_FeOx*	0.956	0.914	281.97
Am_FeOx			
Y= - 193.571 + 0.425 Residual*	0.961	0.921	320.54
Cry_FeOx			
Y= 536.098 + 0.717 Am_FeOx** - 0.218 Residual*	0.977	0.955	213.45
Y= 831.711 + 0.938 Am_FeOx**	0.956	0.914	276.54
Residual			
Y= 225.024 - 1.111 Am_FeOx*	0.925	0.856	496.54
With physicochemical properties			
SE			
Y= 48.316 - 3.654 Clay** - 2.124 pH*	0.909	0.867	82.64
Y= 124.318 + 5.129 Clay**	0.756	0.684	147.34
OB			
Y= - 663.579 +172.555 OC* - 46.32 MnO*	0.918	0.846	177.91
Y= 466.8 + 124.750 OC*	0.745	0.585	280.35
MnOx			
Y= 1.893 + 282.110 MnO*-5.5 Am_Fe*	0.879	0.858	209.45
Y= 232.034 + 64.656 MnO**	0.852	0.805	295.30
Am_FeOx			
Y= - 3246.937 + 535.311 Am_Fe*	0.854	0.814	349.15
Cry_FeOx			
Y= 611.760 - 72.206 Am_Fe *	0.769	0.739	232.37
Residual			
Y= 3192.510 - 84.773 Am_Fe * - 61.047 OC*	0.886	0.872	275.39
Y= 2779.229 - 74.773 Am_Fe *	0.826	0.682	737.79

Organically bound iron (OB-Fe) content is mostly governed by oxidizable organic carbon and manganese oxide content in *Alfisols* (84.6%) while in *Inceptisols*, oxidizable organic carbon largely controls the variation of OB-Fe (84.3%). Among Fe fractions, manganese oxide-bound iron was the major contributory (dictating 69% variation of OB-Fe in *Alfisol* and 63.7% in *Inceptisol*. Variations in MnOx-Fe are mostly governed by manganese oxide content and amorphous iron oxide content of soil (85.8% in *Alfisols*) and manganese oxide content (75.4% in *Inceptisols*) and crystalline iron oxide bound Fe fraction was major contributor (91.4% in *Alfisols* and 92.1% in *Inceptisols*).

Amorphous iron oxide bound fraction is largely impacted by changes in amorphous iron oxide content (81.4 % in *Alfisol* and 72.4% in *Inceptisol*). Residual iron fractions was observed to mostly dictate variations in amorphous iron oxide bound Fe (92.1% in *Alfisols* and 82.1% in *Inceptisols*). Crystalline iron oxide bound fraction is mostly affected by variations in amorphous iron oxide content of *Alfisols* (73.9%) and by variations in amorphous iron oxide and manganese oxide content of *Inceptisols* (89.6%) while amorphous iron oxide was the major contributory (74.4%). Cry_FeOx-Fe was observed further to be largely governed by changes in amorphous iron oxide bound and residual fractions

(95.5% in *Alfisols*) of which amorphous iron oxide bound fraction is the dominant (91.4%) contributor.

Table 11: Relationship and Interrelationship of Fe fractions in *Inceptisols*

	R²	**Adj-R²**	**SEest.**
Between fractions			
SE			
Y= 33.687 + 0.390 OB*	0.693	0.474	102.68
OB			
Y= 440.859 - 0.398 MnOx**	0.831	0.637	233.16
MnOx			
Y= - 456.984 + 1.234 Cry_FeOx*	0.934	0.921	319.87
Am_FeOx			
Y= - 200.98 + 0.697 Residual*	0.924	0.897	345.26
Cry_FeOx			
Y= 852.711 – 1.254 Am_FeOx**	0.889	0.821	384.35
Residual			
Y= 309.024 – 2.956 Am_FeOx*	0.934	0.874	423.56
With physicochemical properties			
SE			
Y= 673.731 + 4.624 Clay**- 4.710 pH**	0.985	0.971	69.23
Y= 42.316 + 12.634 Clay**	0.902	0.814	160.81
OB			
Y= -1846.497 + 424.326 OC**	0.918	0.843	479.64
MnOx			
Y= - 690.934 + 1911.336 MnO*	0.868	0.754	551.78
Am_FeOx			
Y= - 859.621 + 487.254 Am_Fe**	0.761	0.724	428.08
Cry_FeOx			
Y= 1000.752 - 612.236 Am_Fe * - 551.825 MnO*	0.898	0.896	100.16
Y= 2867.75 -428.757 Am_Fe*	0.819	0.744	488.85
Residual			
Y= 6037.938 - 74.194 Am_Fe**	0.867	0.835	671.03

In *Inceptisol*, amorphous iron oxide bound fraction was the sole contributor (82.1%). Residual Fe is mostly governed by variations in amorphous iron content and oxidizable organic carbon content in *Alfisols* (87.2%) of which amorphous iron is the major contributory (68.2%) while in *Inceptisols*, amorphous iron content was the sole determinant (83.5%). Change in residual Cu is mainly dictated by amorphous iron oxide bound fraction (85.6% in *Alfisols* and 87.4% in *Inceptisols*).

Zinc

Total and fractions of soil zinc were statistically regressed against soil physico-chemical properties. The inter relationship between Zn fractions have also been computed to assess the source-sink movement of soil Zn (Table 12-13).

The changes in soluble and exchangeable zinc are mostly governed by soil clay (64.9%) in *Alfisols* and clay content of soil and soil pH (96.4%) in *Inceptisols* while clay content was the most important parameter in *Inceptisol* (81.3%). Soluble and exchangeable zinc was observed to be mostly impacted by changes in organically bound zinc (53.8% in *Alfisols* and 56.7% in *Inceptisols*).

Organically bound zinc (OB-Zn) content is mostly governed by oxidizable organic carbon (76.5% in *Alfisols*) and manganese oxide content plus oxidizable organic carbon (95.1% in *Inceptisols*) and oxidizable organic carbon alone controls the variation of OB-Zn (84.6 %) in *Inceptisols*. Among Zn fractions, organically bound zinc content is mostly controlled by amorphous iron oxide bound zinc (78.2% in *Alfisols* and 84.3% in *Inceptisols*). Variations in MnOx-Zn are mostly governed by manganese oxide content of soil (68.6% in *Alfisols*) and manganese oxide content and soil clay content (93.3% in *Inceptisol*) while manganese oxide content alone controls MnOx-Zn in *Inceptisol* (82.6%). MnOx-Zn was mostly governed by crystalline iron oxide bound fraction (84.7% in *Alfisol*) and (86.7 % in *Inceptisols*). Amorphous iron oxide bound fraction is largely impacted by changes in amorphous iron oxide content in both *Alfisols* (91.1%) and *Inceptisols* (97.7%). Manganese oxide bound Zn fractions was observed to dictate variations in amorphous iron oxide bound Zn (78.2 % in *Alfisols* and 73.2 % in *Inceptisols*).

Table 12: Relationship and Interrelationship of Zn fractions in *Alfisols*

	R²	**Adj-R²**	**SEest.**
Between fractions			
SE			
Y= - 0.055 + 0.149 OB*	0.733	0.538	0.141
OB			
Y= 0.962 + 0.197 Am_FeOx**	0.884	0.782	0.479
MnOx			
Y= 1.702 + 0.92 Cry_FeOx*	0.92	0.847	0.108
Am_FeOx			
Y= - 0.762 + 3.968 MnOx*	0.884	0.782	2.156

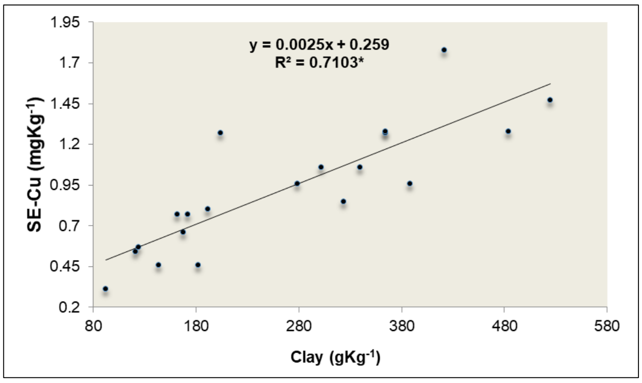
Cry_FeOx			
Y= 6.408 - 0.448 Am_FeOx*	0.940	0.923	0.312
Residual			
Y= 8.917 - 1.992 MnOx*	0.955	0.913	1.248
With physicochemical properties			
SE			
Y= 0.059 + 0.0462 Clay*	0.805	0.649	0.123
OB			
Y= -0.535 + 3.497 OC*	0.875	0.765	0.497
MnOx			
Y= 0.963+ 8.942 MnO*	0.828	0.686	1.551
Am_FeOx			
Y= - 6.828 + 17.130 Am_Fe*	0.954	0.911	1.374
Cry_FeOx			
Y= 19.057 -1.83 Am_Fe*- 0.001 EC*	0.824	0.795	1.130
Y= 21.737-2.901 Am_Fe **	0.734	0.754	1.529
Residual			
Y= 2.296 - 0.801 Am_Fe*	0.768	0.590	2.706

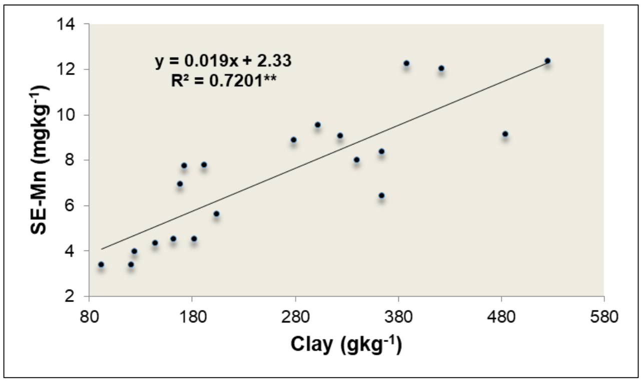
Crystalline iron oxide bound fraction is mostly affected by variations in amorphous iron oxide content and electrical conductivity in *Alfisols* (79.5%) of which amorphous iron oxide content was the major contributory (75.4%) and by variations in amorphous iron oxide alone in *Inceptisols* (78.2%). Cry_FeOx-Zn was observed further to be largely governed by changes in amorphous iron oxide bound fraction (92.3% in *Alfisols* and 80.3% in *Inceptisols*). Changes in residual Zn are mostly dictated by manganese oxide bound fraction in *Alfisols* (91.3%) and Am_FeOx-Zn in *Inceptisols* (88.7%).

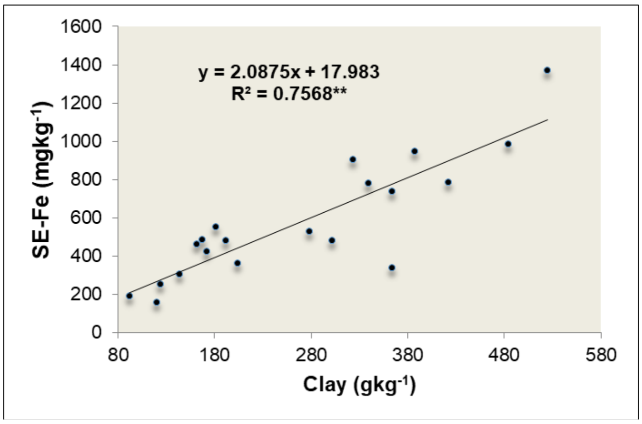
Table 12: Relationship and Interrelationship of Zn fractions in *Inceptisols*

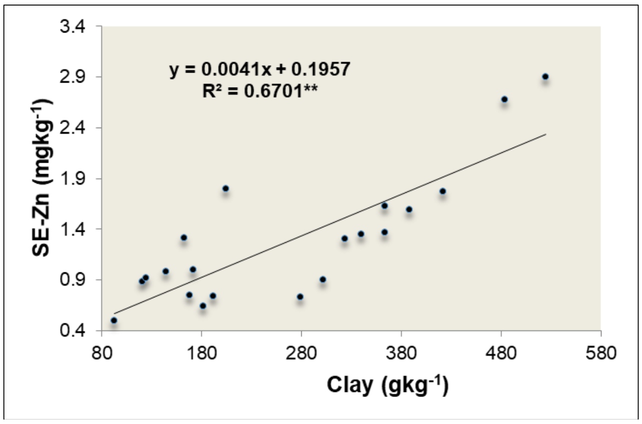
	R^2	**Adj-R^2**	**SEest.**
Between fractions			
SE			
Y= - 0.0635 + 0.193 OB*	0.764	0.567	0.14897
OB			
Y= 1.262 + 0.254 Am_FeOx**	0.861	0.843	0.59986
MnOx			
Y= 1.902 + 0.92 Cry_FeOx **	0.894	0.867	0.1384
Am_FeOx			
Y= - 0.862 + 5.942 MnOx*	0.804	0.732	2.1662
Cry_FeOx			
Y= 8.408 - 0.848 Am_FeOx*	0.840	0.803	0.3923
Residual			
Y= 11.247 – 2.134 Am_FeOx *	0.945	0.915	2.045
With physicochemical properties			
SE			
Y= 0.689 + 0.023 Clay** - 0.32 pH*	0.982	0.964	0.076
Y= - 0.194+0.003 Clay**	0.902	0.813	0.164
OB			
Y= -1.011 + 4.168 OC** -0.0233 MnO*	0.975	0.951	0.567
Y= 3.414 + 3.988 OC**	0.92	0.846	0.938
MnOx			
Y= -0.813 + 9.582 MnO** - 0.004 Clay*	0.987	0.933	0.270
Y= 0.44+ 14.583 MnO**	0.884	0.826	0.556
Am_FeOx			
Y= 2.584 + 11.680 Am_Fe*	0.989	0.977	0.822
Cry_FeOx			
Y= 1.018 - 4.821 Am_Fe *	0.791	0.782	0.489
Residual			
Y= 12.783 - 6.019 Am_Fe*	0.894	0.887	0.946

Among all the fractions of micronutrient studied, SE fractions are reported to be most dominant one from the viewpoint of plant availability. To understand the dependency of SE fractions of all the concerned element on the soil physicochemical properties obtained from step wise regression the following scatter diagrams have been prepared.









Discussions

The total manganese content of the selected soils ranged from 214.21-510.96 $mgkg^{-1}$ which was more or less in good agreement with the findings of Shuman (1979) [57] and Singh *et al*. (1988) [64]. The exchangeable manganese content was quite low (less than 2%) as found by Singh *et al*. (1988) [64]. The manganese bound to organic matter was significantly higher than reported by Singh *et al*. (1988) [64]. The preference of this metal towards organic matter may be supported by their high stability constant (Gonzalez *et al*., 1994; Ramzan and Bhat, 2017) [18, 55]. The dissolution of this iron and manganese oxide bound mineral controls mobility and bioavailability (Bhattacharya *et al*., 2006) [6]. The crystalline and amorphous iron bound manganese fractions was significantly lower than fractions associated with manganese oxide which possibly suggests that manganese has a tendency to be associated with Mn-oxides rather than the Fe-oxides. Such findings were also reported by Gibbs (1973) [66], Tessier *et al*. (1979) [72] and Singh *et al*. (1988) [64], although opposed by Shuman (1985) [58] who found significantly higher association of manganese with organic fractions rather than Mn-oxide fractions. The residual fraction was comparatively lower than suggested by Shuman (1985) [58]; Singh *et al*. (1988) [65]; Kumar and Babel (2011) [29] and Gao *et al*. (2018) [15].

The total copper of the selected soils were in the range 30.14-68.32 mg kg^{-1} in good agreement with the findings of McLaren and Crawford, 1973 [40]; Shuman 1979 [57], 1985; Miller *et al*., 1986 [43] and Singh *et al*., 1988 [65]. The exchangeable copper content was also within the range of 1-7% as reported by Shuman, 1979 [57] and Singh *et al*., 1988 [65]. The low content of exchangeable copper may be attributed to leaching and plant uptake as have been reported by Filgueiras *et al*., 2002 [14] and Kabata-Pendias, 2011 [25]. The organically bound copper was found to be significantly higher in contrast to the findings of Singh *et al*., 1988 [65] but in good agreement with McLaren and Crawford, 1973 [40] and Miller and McFee, 1983 [42]. This is an important consideration as has been reported by Havlin *et al*., 2012 [19] who observed that copper is more strongly bound to organic matter than any other micronutrient. The soil copper associated with Mn-oxide, amorphous and crystalline iron fractions were significantly higher than reported by Shuman, 1985 [58] and Singh *et al*., 1988 [65]. Our findings can be attributed to the reports of Kabata-Pendias and Pendias, 2001 [26] and Oviasogie *et al*., 2011 [51] who found that Fe-Mn bound copper was one of the major dominant fractions in alluvial soils of Nigeria. Such higher fractions of Fe/Mn-Cu has also been reported by Havlin *et al*., 2012 [19] who suggested strong surface bonding of copper with metal oxides. However, 30-40% of the residual Cu fractions was telatively lower than previous findings (McLaren and Crawford, 1973; Shuman, 1979, 1985; Miller *et al*., 1986; Singh *et al*., 1988) [57, 40, 65, 43, 64] which may be due to high weathering of copper bound minerals and transformation (Kabata-Pendias, 2011; Fathi *et al*., 2014; Okoli *et al*., 2019) [25, 12, 49].

The total iron content of the selected soils ranged from 1.06% to 5.03% which is within the range of 0.5 to 5% normally found in soils and the exchangeable iron content was quite low (less than 2%) as found by Singh *et al*., 1988 [65]. The organically bound iron fraction (8-12%) was significantly higher than obtained by Wei *et al*., 2010 [75] and Xing and Zhu, 2003 [76] possibly having a high chemical stability constant (Mackowiak *et al*., 2001) [33]. The iron content in manganese oxide bound fraction was found to be low whereas the amorphous iron and crystalline iron bound fractions were found to be significantly higher than reported by others (Tessier *et al*., 1979; Shuman, 1985; Sims and Patrick; 1978; Singh *et al*., 1988; Zheng *et al*., 2003; Fiedler and Sommer, 2004 and Wei *et al*., 2010) [71, 58, 63, 64, 78, 13, 75] who found that bulk of the soil iron was found in residual and crystalline iron fractions.

The total zinc content of the selected soils ranged from 30.83-108.46 $mgkg^{-1}$ which was found to be similar to that obtained by Singh *et al*., 1988 [65]. In a separate study in North

American soil, Lindsay (1972) [30] reported a total zinc content of 10-300 mgkg^{-1}, bearing a more or less similar trend. The zinc content in the exchangeable fraction was found to be <2% which is similar to the findings of Singh *et al*., 1988 [64]; Shuman, 1979, 1985 [57, 58]; Iyengar *et al*., 1981 [22] and Sims, 1988 [62]. The organically bound fraction of zinc (7-12% of the total) was similar to the comparatively higher content of the said fraction in other studies (Iyengar *et al*., 1981; Shuman, 1985; Sims, 1988) [22, 58, 62] and in sharp contrast with findings of Singh *et al*., 1988 [65]. Zinc associated with amorphous and crystalline iron oxide fractions were higher than the manganese oxide bound fraction which may possibly indicate a greater contributory role of iron oxides in the chemistry of zinc in the soil rather than Mn-oxide fractions. Such findings were well corroborated by observations of Shuman, 1985 [58] and Singh *et al*., 1988 [65] but differed from Neilsen, 1990 who propounded a larger content of zinc in the Mn-oxide fraction. The undetermined pool envisaged as residual fraction was found to be in the range of 25 – 33% (of total Zn) which was somewhat lower than reported by Iyengar *et al*., 1981 [22]; Shuman, 1979 [57], 1985 [58]; Singh *et al*., 1988 [65] and Neilsen, 1990. However, the findings that Fe-Mn bound and residual fraction of zinc attributes more than 80% of the total pool is in good agreement with the findings of Brunetto *et al*., 2014 [9]; de Rosa Couto *et al*., 2014 [10] and Beygi and Jalali, 2019 [5].

The relationships and interrelationships of Mn fractions are quiet in good agreements with the findings of Narender *et al*., 2016 [47] for SE-Mn; Agbenin, 2003 [1] and Narender *et al*., 2016 [47] for OB-Mn; Herbert *et al*., 1998 [20]; Ariza *et al*., 2000 [2] for MnOx, Am_FeOx and Cry_FeOx fractions. The relationships and interrelationships of Cu fractions are found to be similar with the findings of Karin *et al*. 1976 and Sun *et al*. 2019 [69] for OB-Cu; Arora and Sekhon, 1980 [3] for SE-Cu; McBride and Bouldin, 1984 [38] for MnOx, Am_FeOx and Cry_FeOx fractions. The relationships and interrelationships of Fe fractions are quiet in good agreements with the findings of Shuman, 1988 [59] and Agbenin, 2003 [1] for SE-Fe; Agbenin, 2003 [1] for OB-Fe; Munch and Ottow, 1980 [46] and Sun *et al*., 2019 [69] for MnOx, Am_FeOx and Cry_FeOx fractions. The relationships and interrelationships of Zn fractions are found to be similar with the findings of López-Valdivia *et al*., 2002 [32] and Soltani *et al*., 2015 [67] for SE-Zn; Soltani *et al*., 2015 [67] for OB-Zn; Katyal and Sharma, 1991 [27]; Soltani *et al*., 2015 [67] Rajini *et al*. 2018 [54] for MnOx, Am_FeOx and Cry_FeOx fractions.

Conclusion

The study was carried out to have a clear idea about the water-soluble and exchangeable; organically bound; manganese oxide–bound/occluded, amorphous iron oxide-bound, crystalline oxide-bound fractions of the cationic micronutrients (Zn, Cu, Fe, Mn) in the soils of two agriculturally important soil orders of West Bengal i.e. Alfisol and Inceptisol.The largest fractions of Mn, Cu, Fe and Zn were MnOx-Mn, OB-Cu, Cry_FeOx-Fe and Am_FeOx-Zn in both the soil orders. The soluble and exchangeable fraction which most dominantly contributes to plant availability was observed to be significantly governed by the clay content and soil pH and organically bound fractions.

Thus, by manipulating the concerned soil factors, the availability status of micronutrients can be altered. The agricultural significance in the form of rice cultivation can exhibit varying moisture and organic status affecting nutrient availability by changing the initial soil pools, ushering special significance to our study.

References

1. Agbenin JO. The distribution and transformation of iron and manganese in soil fractions in a savanna Alfisol under continuous cultivation. Nutrient cycling in agroecosystems. 2003; 66(3):259-270.
2. Ariza JG, Giráldez I, Sánchez-Rodas D, Morales E. Comparison of the feasibility of three extraction procedures for trace metal partitioning in sediments from south-west Spain. Science of the total environment. 2000; 246(2-3):271-283.
3. Arora CL, Sekhon GS. Influence of soil characteristics on DTPA extractable micronutrient cations in some soil series of Punjab. Journal of the Indian Society of Soil Science. 1981; 29(4):453-461.
4. ASK. Saskatchewan Agriculture. Micronutrients in Crop Production. Soils, Fertility and Nutrients. ASK Saskatchewan Agriculture, 2012. http://www.agriculture.gov.sk.ca/
5. Beygi M, Jalali M. Assessment of trace elements (Cd, Cu, Ni, Zn) fractionation and bioavailability in vineyard soils from the Hamedan, Iran. *Geoderma*. 2019; 337:1009-1020.
6. Bhattacharya P, Chakraborty A, Chakrabarti K, Tripathy S, Powell MA. Copper and zinc uptake by rice and accumulation in soil amended with municipal solid waste compost. Environmental Geology. 2006; 49:1064-1070.
7. Bouyoucos GJ. Hydrometer method improved for making particle size analyses of soils. Agron. J. 1962; 54(5):464-465.
8. Bray RH, Kurtz LT. Determination of total, organic, and available forms of phosphorus in soils. Soil science. 1945; 59(1):39-46.
9. Brunetto G, Miotto A, Ceretta CA, Schmitt DE, Heinzen J, de Moraes MP *et al*. Mobility of copper and zinc fractions in fungicide-amended vineyard sandy soils. Archives of Agronomy and Soil Science. 2014; 60(5):609-624.
10. de Rosa Couto R, Benedet L, Comin JJ, Belli Filho P, Martins SR, Gatiboni LC *et al*. Accumulation of copper and zinc fractions in vineyard soil in the mid-western region of Santa Catarina, Brazil. Environmental earth sciences. 2015; 73(10):6379-6386.
11. Eskandari H. The importance of iron (Fe) in plant products and mechanism of its uptake by plants. J Appl. Environ. Biol. Sci. 2011; 1(10):448-452.
12. Fathi H, Aryanpour H, Fathi H, Moradi H. Distribution of zinc and copper fractions in acid and alkaline (highly calcareous) soils of Iran. Sky Journal of Soil Science and Environmental Management. 2014; 3(1):6-13.
13. Fiedler S, Sommer M. Water and redox conditions in wetland soils-their influence on pedogenic oxides and morphology. Soil Science Society of America Journal. 2004; 68(1):326-335.
14. Filgueiras AV, Lavilla I, Bendicho C. Chemical sequential extraction for metal partitioning in environmental solid samples. Journal of Environmental Monitoring. 2002; 4(6):823-857.
15. Gao X, Chen S, Long A. Chemical speciation of 12 metals in surface sediments from the northern South China Sea under natural grain size, 2008.
16. Gibbs RJ. Mechanisms of trace metal transport in rivers. Science. 1973; 180(4081):71-73.

17. Golui D, Barman M, Datta SP, Shukla AK. Fractionation of micronutrients and metals in soil. In Manual on Advance Techniques for Analysis of Nutrients and Pollutant Elements in Soil, Plant and Human (S.P. Datta, M.C. Meena, B.S. Dwivedi and A.K. Shukla, Eds). Westville Publishing House, New Delhi, 2017. (ISBN 978-93- 83491-87-2).
18. Gonzalez MJ, Ramos L, Hernandez LM. Organochlorine and heavy metal residues in the water/sediment system of the Southeast Regional Park in Madrid, Spain. International Journal of Environmental Analytical Chemistry. 1994; 57:135-140.
19. Havlin JL, Hardy DH, Gehl RJ, Spayd SE. Survey of nutrient status in Vitis vinifera grapes in North Carolina. Communications in soil science and plant analysis. 2012; 43(1-2):299-314.
20. Herbert Jr RB, Benner SG, Pratt AR, Blowes DW. Surface chemistry and morphology of poorly crystalline iron sulfides precipitated in media containing sulfate-reducing bacteria. Chemical Geology. 1998; 144(1-2):87-97.
21. Horváth B, Opara-Nadi O, Beese F. A Simple Method for Measuring the Carbonate Content of Soils. Soil Science Society of America Journal. 2005; 69:1066-1068. http://dx.doi.org/10.2136/sssaj2004.0010
22. Iyengar SS, Martens DC, Miller WP. Distribution and Plant Availability of Soil Zinc Fractions 1. Soil Science Society of America Journal. 1981; 45(4):735-739.
23. Jackson ML. Soil Chemical Analysis. New Delhi, Prentice Hall, 1967.
24. Jackson ML. Soil Chemical Analysis. New Delhi, Prentice Hall, 1973.
25. Kabata-Pendias A. Trace elements in soils and plants, Fourth Ed, 2011.
26. Kabata-Pendias A, Pendias H. Trace elements in soils and plants–CRC Press. Boca Raton, 2001.
27. Katyal JC, Sharma BD. DTPA-extractable and total Zn, Cu, Mn, and Fe in Indian soils and their association with some soil properties. Geoderma. 1991; 49:165-179.
28. Knudsen D, Peterson GA, Pratt PF. Lithium, sodium, and potassium. Methods of soil analysis. Part 2. Chemical and microbiological properties, 1982, 225-246.
29. Kumar M, Babel AL. Available micronutrient status and their relationship with soil properties of Jhunjhunu tehsil, District Jhunjhunu, Rajasthan, India. Journal of Agricultural Science (Toronto). 2011; 3(2):97-106.
30. Lindsay WL. Inorganic phase equilibria of micronutrients in soils. Micronutrients in agriculture, 1972, 41-57.
31. Lindsay WL, Norvell WA. Development of a DTPA Soil Test for Zinc, Iron, Manganese, and Copper. Soil Sci Soc Am J. 1978; 42(3):421-428.
32. Lopez-Valdivia LM, Fernandez MD, Obrador A, Alvarez JM. Zinc transformations in acidic soil and zinc efficiency on maize by adding six organic zinc complexes. Journal of agricultural and food chemistry. 2002; 50(6):1455-1460.
33. Mackowiak CL, Grossl PR, Bugbee BG. Beneficial effects of humic acid on micronutrient availability to wheat. Soil Science Society of America Journal. 2001; 65(6):1744-1750.
34. Maleki A, Feizolahi A, Daneshian J, Naseri R, Rashnavadi R. Effect of different sources of nitrogen and zinc sulfate on grain yield and its associated traits in marigold (*Calendula officinalis*. L). International Journal of Biosciences. 2014; 4(6):45-52.
35. Mandal LN, Mandal B. Transformation of zinc fractions in rice soils. Soil science. 1987; 143(3):205-212.
36. Mandal LN, Mitra RR. Transformation of iron and manganese in rice soils under different moisture regimes and organic matter applications. Plant and Soil. 1982; 69(1):45-56.
37. Marschner H. Marschner's mineral nutrition of higher plants. Academic press, 2011.
38. McBride MB, Bouldin DR. Long-Term Reactions of Copper (II) in a Contaminated Calcareous Soil 1. Soil Science Society of America Journal. 1984; 48(1):56-59.
39. McKeague JA, Day J. Dithionite-and oxalate-extractable Fe and Al as aids in differentiating various classes of soils. Canadian Journal of Soil Science. 1966; 46(1):13-22.
40. McLaren RG, Crawford DV. Studies on soil copper. I. The fractionation of copper in soils. J Soil Sci. 1973; 24:172-181.
41. Millaleo R, Reyes-Díaz M, Ivanov AG, Mora ML, Alberdi M. Manganese as essential and toxic element for plants: transport, accumulation and resistance mechanisms. Journal of soil science and plant nutrition. 2010; 10(4):470-481.
42. Miller WP, Mc Fee WW. Distribution of Cadmium, Zinc, Copper, and Lead in Soils of Industrial Northwestern Indiana 1. Journal of Environmental Quality. 1983; 12(1):29-33.
43. Miller WP, Martens DC, Zelazny LW. Effect of Sequence in Extraction of Trace Metals from Soils 1. Soil Science Society of America Journal. 1986; 50(3):598-601.
44. Moreira A, Moraes LAC, Souza LGM, Bruno IP. Bioavailability of nutrients in seeds from tropical and subtropical soybean varieties. Communications in Soil Science and Plant Analysis. 2016; 47(7):888-898.
45. Mousavi SR, Shahsavari M, Rezaei M. A general overview on manganese (Mn) importance for crops production. Australian Journal of Basic and Applied Sciences. 2011; 5(9):1799-1803.
46. Munch JC, Ottow JCG. Preferential reduction of amorphous to crystalline iron oxides by bacterial activity. Soil Science. 1980; 129(1):15-21.
47. Narender RS, Yadav K, Yadav HK. Fractionation and Distribution of Manganese in Different Cropping System and Their Relationship with Soil Properties in Haryana. Environment & Ecology. 2016; 34(4D):2533-2540.
48. Nielsen JRD. Specific zinc adsorption as related to the composition and properties of clay and silt in some Danish soils. *Acta Agriculturae Scandinavica*. 1990; 40(1):3-9.
49. Okoli NH, Uzoho BU, Ihem EE, Okon MA. Differential speciation and availability of copper in soils derived from different parent materials in Imo State, southeastern Nigeria. Agro-Science. 2019; 18(1):7-15.
50. Olsen SR, Sommers LE. Phosphorus. AL *et al*. (ed.) Methods of soil analysis. Part 2. *Agron. Monogr.* 9. ASA and SSSA, Madison, WI, 1982, 403-430.
51. Oviasogie PO, Aghimien AE, Ndiokwere CL. Fractionation and bioaccumulation of copper and zinc in wetland soils of the Niger Delta determined by the oil palm. Chemical Speciation & Bioavailability. 2011; 23(2):96-109.

52. Pandey N, Pathak GC, Singh AK, Sharma CP. Enzymic changes in response to zinc nutrition. Journal of Plant Physiology. 2002; 159(10):1151-1153.
53. Phillips I, Chappie L. Assessment of a heavy metals-contaminated site using sequential extraction, TCLP, and risk assessment techniques. Soil and Sediment Contamination. 1995; 4(4):311-325.
54. Rajini SR, Narayana Rao K, Bharath Kumar KS. Distribution of zinc forms in paddy soils of upper Krishna project command area of north Karnataka. In Compendium of abstracts of the 2nd international conference on bio-resource and stress management. ANGRAU & PJTSAU, Hyderabad, 2018, 7-10.
55. Ramzan S, Bhat MA. Distribution of Geochemical fractions of Zn, Fe, Cu and Mn under different landuses of Temperate Himalayas. IJCS. 2017; 5(3):734-744.
56. Shukla K, Anshumali. Soil micronutrient pools and their transfer to paddy-crops in semi-arid agro-ecosystems, Central India. Soil and Tillage Research. 2018; 180:164-174.
57. Shuman LM. Zinc, manganese, and copper in soil fractions. Soil Science. 1979; 127(1):10-17.
58. Shuman LM. Fractionation method for soil microelements. Soil science. 1985; 140(1):11-22.
59. Shuman LM. Effect of organic matter on the distribution of manganese, copper, iron, and zinc in soil fractions. Soil Science. 1988; 146(3):192-198.
60. Shuman LM. Effect of organic matter on the distribution of manganese, copper, iron, and zinc in soil fractions. Soil Science. 1988; 146(3):192-198.
61. Shuman LM. Chemical forms of micronutrients in soils. Micronutrients in agriculture, (micronutrientsi2), 1991, 113-144.
62. Sims IT. Fate of heavy metals in organic wastes produced by the Delaware Solid Waste Authority. Newark Proj. Rep., Univ. of Delaware, Newark, DE, 1988.
63. Sims JL, Patrick WH. The Distribution of Micronutrient Cations in Soil under Conditions of Varying Redox Potential and pH 1. Soil Science Society of America Journal. 1978; 42(2):258-262.
64. Singh JP, Karwasra SPS, Singh M. Distribution and forms of copper, iron, manganese, and zinc in calcareous soils of India. Soil Science. 1988; 146(5):359-366.
65. Singh JP, Karwasra SPS, Singh M. Distribution and forms of copper, iron, manganese, and zinc in calcareous soils of India. Soil Science. 1988; 146(5):359-366.
66. Singh R, Kundu DK, Kumar A. Characterisation of Dominant Soil Subgroups of Eastern India for Formulating Water Management Strategies, 2009.
67. Soltani S, Hanafi MM, Wahid SA, Kharidah SMS. Zinc fractionation of tropical paddy soils and their relationships with selected soil properties. Chemical Speciation & Bioavailability. 2015; 27(2):53-61.
68. Subbiah B, Asija GL. Alkaline permanganate method of available nitrogen determination. Curr Science. 1956; 25:259.
69. Sun Q, Li T, Alva AK, Li YC. Mobility and fractionation of copper in sandy soils. Environmental Pollutants and Bioavailability. 2019; 31(1):18-23.
70. Tavakoli MT, Chenari AI, Rezaie M, Tavakoli A, Shahsavari M, Mousavi SR. The importance of micronutrients in agricultural production. Advances in Environmental Biology, 2014, 31-36.
71. Tessier A, Campbell PG, Bisson M. Sequential extraction procedure for the speciation of particulate trace metals. Analytical chemistry. 1979; 51(7):844-851.
72. Tessier A, Campbell PG, Bisson M. Sequential extraction procedure for the speciation of particulate trace metals. Analytical chemistry. 1979; 51(7):844-851.
73. Viets Jr, FG. Micronutrient availability, chemistry and availability of micronutrients in soils. Journal of Agricultural and Food Chemistry. 1962; 10(3):174-178.
74. Walkley A, Black IA. An examination of the Degtjareff method for determining soil organic matter, and a proposed modification of the chromic acid titration method. Soil sci. 1934; 37(1):29-38.
75. Wei X, Shao M, Zhuang J, Horton R. Soil iron fractionation and availability at selected landscape positions in a loessial gully region of northwestern China. Soil Science & Plant Nutrition. 2010; 56(4):617-626.
    www.matirkotha.net
76. Xing GX, Zhu JG. Soil Chemistry of Trace Elements and Rare Earth Elements. Science Press, Beijing (in Chinese), 2003.
77. Yadegari M, Shakerian A. Irrigation periods and Fe, Zn foliar application on agronomic characters of Boragoofficinalis, Calendula officinalis, Thymus vulgarisand Alyssum desertorum. Advances in Environmental Biology, 2014, 1054-1063.
78. Zheng Y, Zhang F, Li L. Iron availability as affected by soil moisture in intercropped peanut and maize. Journal of plant nutrition. 2003; 26(12):2425-2437.