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Suitability of Different Extractants for Estimation of Cationic Micronutrients in Lateritic Soils of West Bengal

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ABSTRACT

The present study was conducted at Institute of Agriculture (Palli Siksha Bhavana), Visva-Bharati West Bengal, India during 2019–20 to evaluate the extractability of different extractants for extraction of cationic micronutrients in lateritic soils of West Bengal under rice based cropping system. Fifty surface (0–15 cm) samples were collected from rice-based cropping systems from five different blocks of Birbhum district. The pH of the soil was found extremely acidic to slightly acidic. The organic carbon content (%) were low to medium range. Among major nutrients available phosphorus and sulphur showed deficiency under study area. The micronutrients cations were extracted from the soils using five different extractants, namely, Mehlich 3, HCl, AB-DTPA and the conventional extractant DTPA. The greatest mean concentration for all the micronutrients was obtained by Melich 3 extractant followed by HCl whereas the lower values were obtained when DTPA extractant used. Themagnitude of extraction for all cationic micronutrients was Mehlich 3>HCl>AB-DTPA>DTPA. Melich 3 has a higher extractability due to its high pH and ability to displace exchangeable cations due to the presence of the NH_4^+ ion in the extractant. The low extractability of the DTPA extractant may be due to disruption of metal-chelate equilibria in acidic soils. A higher positive significant correlation observed among the extractants from the study indicated that, they were able to extract the micronutrients from remarkably similar pools.

KEYWORDS: Correlation, extractants, lateritic, melich, micronutrients

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1. INTRODUCTION

Soil micronutrients' importance has escalated over the past decade as a consequence of new research manifesting their critical role in plant growth and animal nutrition (Gupta et al., 2008, Sarwar et al., 2010). Even though their requirements in plants are less, they are irreplaceable for the growth and development of plants as macronutrients (Thapa et al., 2021, Fageria, 2007). Micronutrients are involved in various metabolic and enzymatic activities, so that plants will suffer from physiological stresses (Jan et al., 2022) caused by the inefficiency of several enzymatic systems and other related metabolic functions if these elements are not available in sufficient quantities (Barker and Pilbeam, 2015, Rutkowska et al., 2014, Rengel, 2007, Gao et al., 2008). Since micronutrients are indispensable, their deficiency and toxicity may have an adverse influence on crop growth and development (Katyal, 2018, Ibrahim and Abubakar, 2013, Bell and Dell, 2008, Tisdale et al., 1995). Variations in soil micronutrient deficiency levels are really a global phenomenon these days (Cakmak and Kutman, 2018, De-Regil et al., 2013, Bailey et al., 2015, Voortman and Bindraban, 2015, Monreal et al., 2016). For various reasons, micronutrient deficiency has become a major constraint to productivity and sustainability in many Indian soils (Baldantoni et al., 2019, Athokpam et al., 2016, Shambhavi et al., 2018). Singh et al. (2017) reported that almost 50% of Indian soils are deficient in cationic micronutrients. Other resources may also be wasted due to the lack of micronutrients (Samreen et al., 2017). Soil pH is one of the most critical parameterfor micronutrient availability (Wang et al., 2022). The availability of these nutrients decreases when soil pH rises, with the exception of Mo, whose availability rises as soil pH rises (Gupta et al., 2008). According to research findings, soil organic matter plays a major role in soil micronutrient levels and it is a good indicator for the status of nutrient management (Srinivasan et al., 2017, Dhaliwal et al., 2019). Several factors govern the availability of micronutrients, such as their naturally low total concentrations, chemical fractions, soil organic matter, pH, soil-plant/soil-microbe interactions, and plant genotype (Shi et al., 2018, Shukla et al., 2015, Rengel, 2015, Ray and Banik, 2016, Agrawal et al., 2016). Soil testing is an integral component of any nutrient management programme and it is the most cost-effective and most authentic of the different diagnosing tools (Van Raij, 1998). It provides the available status of soil nutrients and will be useful for proper nutrient management (Hegde et al., 2021). Several approaches to analyzing the elements in soil have been developed and introduced in recent years (Jones, 1998). There are several extraction procedures available for estimation of soil micronutrient cation (Mn, Cu, Zn and Fe) status in the soil (Korzeniowska andStanislawska-Glubiak, 2013, Da Fonseca et al., 2010, Shittu et. al., 2010). Among the different chemical extractants, 0.1 μL^{-1} HCl, Mehlich III and the chelates, such as DTPA and EDTA (Lindsay and Norvell, 1978) and AB-DTPA are primarily used. These methods' procedures and principles differ substantially. However, the lack of standardized extraction procedures can impact the reliability of the analytical results. Despite the uncertain outcomes of DTPA extractant in acidic soils, our research relies on it due to its ease of operation (Norvell, 1984). However, the information regarding the use of different extractants for the estimation of cationic micronutrients in Birbhum district is scarce. The goal of this study was to evaluate the efficacy of various extractants for soils from rice-based cropping systems and to identify the best extractant for the soils under evaluation. This study also focused on relationships between the cationic micronutrient levels and their relationships between different physico-chemical properties.

2. MATERIALS AND METHODS

2.1. Description of the study sites

The research area was located between 23°32'30" (right above the tropic of cancer) and 24°35'0" North latitude and 87°5'25" and 88°1'40" East longitudes, with a total area of 4,545 km^2. It's bordered by districts and rivers. The river Ajay passes between the districts of Birbhum and Bardhaman.Jharkhand state borders on the north and west, and Murshidabad borders on the east.

2.2. Sampling and analyses

Surface soil (0–15 cm) was sampled from fifty locations covering rice-based cropping systems from five different blocks of Birbhum district, namely Bolpur, Illembazar, Labpur, Sainthia and Md. Bazar.Collected soil samples were processed and properly labeled for the analysis. Basic physico-chemical properties were analyzed by using standard protocols in the soil testing laboratory under the department of soil science and agricultural chemistry, Visva-Bharati, West Bengal, India during 2019–20. Bouyoucos hydrometer method (1927) was followed for the mechanical analysis of the soil (Black, 1965). Soil pH and electrical conductivity was determined at 1:2.5 soil water suspensions by potentiometric and conductometry method (Jackson, 1973). Organic carbon was measured by wet digestion method (Walkley and Black, 1934). The cation exchange capacity (CEC) was determined using the procedure described by Schollenberger and Simons (1945). Major nutrients, available nitrogen (Subbiah and Asija, 1956), available phosphorus (Bray and Kurtz, 1945), available potassium (Jackson, 1973) and available sulphur (Williams and Steinberg, 1959) levels of soils also were analyzed. Four major chemical extractants were employed for estimation of cationic micronutrient in soilto find the suitable extractant for the study area with the help of Atomic Absorption Spectrophotometer (Table 1).

Table 1: Summary of extraction methods used for extraction of cationic micronutrient in the experiment

Extractants	Extractants composition	Soil: extractant ratio	Shaking time and (Reference)
DTPA	0.005M DTPA+0.1M TEA+ 0.01M $CaCl_2$, pH 7.3	1:2	2hrs (Lindsay and Norvell, 1978)
AB-DTPA	Mixture of 1.0 M NH_4HCO_3 and 0.5 M DTPA, pH 7.6	1:2	15 min (Soltanpour and Schwab, 1977)
HCl	0.1 N HCl	1:5	30 min (Osiname et al., 1973)
Mehlich-3	0.2 MHOAc, 0.25 M NH_4NO_3, 0.015 M NH_4F, 0.013 M HNO_3 and 0.001 M EDTA (pH 2.5±0.1)	1:10	5 min (Mehlich, 1984)

2.3. *Statistical analyses*

Simple correlation coefficients between the amounts of cationic micronutrients extracted by different extractants and other physico-chemical characteristics were evaluated by using the windows-based SPSS programme and following the methodology described by Gomez and Gomez (1984).

3. RESULTS AND DISCUSSION

3.1. *Physico-chemical properties*

Data regarding the physico-chemical properties of surface soils from five different blocks of Birbhum districts is presented in (Table 1–6). The bulk density of soils under investigation varies from 1.21–1.54 g cc^{-1} with a mean value of 1.37 g cc^{-1}. The pH of the soil was found to range from extremely acidic to slightly acidic, with a range of 4.12 to 6.34 and an average value of 5.32. The minimum pH (4.12) was observed in both Bolpur and Illembazar block soils and the maximum value was observed in Bolpur block of Birbhum district. On the basis of the limits suggested by Muhar et al, (1963) for judging salt problem of soils, most of the samples were found normal (EC<1.0 dS m^{-1}) in the category of soluble salt content critical for germination (EC 1 to 2 dS m^{-1}). Through the mechanical analysis itwas found that, the clay content of the study area varied from 12.72 to 51.60%. The organic carbon content (%) of most of the soils under the study showed low to medium range. The lowest organic carbon content (0.15%) was observed in soils of Dubrajpur block, where higher values observed

Table 2: Physico-chemical properties of lateritic soils of Dubrajpur block of Birbhum District, West Bengal

Sample	BD (g cc^{-1})	pH	EC (ds m^{-1})	Clay (%)	OC (%)	CEC [C mol (P+) kg^{-1}]	N (kg ha^{-1})	P_2O_5 (kg ha^{-1})	K_2O (kg ha^{-1})	S (mg kg^{-1})
S_1	1.25	5.21	0.08	40.44	0.44	10.2	206.87	24.35	166.8	6.22
S_2	1.29	6.34	0.05	51.6	0.58	14.6	340.31	18.25	148.24	9.35
S_3	1.39	5.89	0.15	30.16	0.25	8.5	285.4	34.87	231.57	5.25
S_4	1.43	5.13	0.16	23.44	0.56	6.3	220.56	37.14	295.41	6.06
S_5	1.29	6.14	0.09	40.16	0.32	11.5	263.74	20.1	175.15	9.63
S_6	1.30	6.07	0.11	42.6	0.53	10.3	334.52	28.79	254.26	8.86
S_7	1.41	5.1	0.13	21.44	0.31	6.2	243.28	41.22	268.51	5.09
S_8	1.38	5.31	0.07	23.44	0.25	7.8	223.57	34.76	229.47	7.51
S_9	1.42	5.42	0.12	22.16	0.42	6.4	201.31	33.51	288.91	8.37
S_{10}	1.44	6.25	0.09	42.16	0.15	11.2	241.15	24.28	154.66	9.54
Range	1.25–1.44	5.10–6.34	0.05–0.16	21.44–51.60	0.15–0.58	6.20–14.60	201.31–340.31	18.25–41.22	148.24–295.41	5.09–9.63
Mean	1.36	5.69	0.11	33.76	0.38	9.30	256.07	29.73	221.30	7.59
SD	0.07	0.50	0.04	10.88	0.15	2.75	49.77	7.72	56.20	1.80

Table 3: Physico-chemical properties of lateritic soils of Sainthia block of Birbhum District, West Bengal

Sample	BD (g cc^{-1})	pH	EC (ds m^{-1})	Clay (%)	OC (%)	CEC [C mol (P+) kg^{-1}]	N (kg ha^{-1})	P_2O_5 (kg ha^{-1})	K_2O (kg ha^{-1})	S (mg kg^{-1})
S_1	1.35	5.21	0.16	35.6	0.44	7.3	246.35	25.32	298.25	7.86
S_2	1.41	5.08	0.12	20.16	0.65	6.8	296.57	14.34	175.34	9.63
S_3	1.33	5.88	0.17	20.16	0.73	7.1	342.14	27.26	275.14	7.22
S_4	1.27	4.54	0.11	41.6	0.56	10.1	372.1	17.37	142.36	8.06
S_5	1.48	5.04	0.12	22.16	0.66	6.2	342.91	21.65	195.64	9.09
S_6	1.36	5.59	0.16	33.44	0.49	9.7	254.12	26.27	265.97	9.84
S_7	1.21	4.76	0.09	42.32	0.68	11.2	335.11	18.79	321.21	8.35
S_8	1.52	5.87	0.14	14.16	0.71	8.4	264.45	26.41	251.17	6.25
S_9	1.25	4.95	0.09	41.6	0.47	10.8	378.24	15.98	172.54	8.51
S_{10}	1.39	4.83	0.08	51.6	0.52	11.3	274.51	16.37	131.25	6.37
Range	1.21–1.52	4.54–5.88	0.08–0.17	14.16–51.60	0.44–0.73	6.20–11.30	246.35–378.24	14.34–27.26	131.25–321.21	6.25–9.84
Mean	1.36	5.18	0.12	32.28	0.59	8.89	310.65	20.98	222.89	8.12
SD	0.10	0.46	0.03	12.40	0.11	1.96	49.38	4.99	67.62	1.24

Table 4: Physico-chemical properties of lateritic soils of Illambazar block of Birbhum District, West Bengal

Sample	BD (g cc^{-1})	pH	EC (ds m^{-1})	Clay (%)	OC (%)	CEC [C mol (P+) kg^{-1}]	N (kg ha^{-1})	P_2O_5 (kg ha^{-1})	K_2O (kg ha^{-1})	S (mg kg^{-1})
S_1	1.30	5.64	0.11	44.88	0.72	12.3	354.52	20.19	274.05	9.4
S_2	1.42	6.25	0.14	25.44	0.41	6.9	297.85	33.88	285.34	8.12
S_3	1.38	6.22	0.19	30.32	0.39	13.5	286.34	36.53	263.18	8.06
S_4	1.39	6.59	0.26	22.88	0.49	7.5	321.52	33.14	305.24	6.99
S_5	1.42	5.84	0.16	41.44	0.73	8.9	357.21	11.56	241.29	8.72
S_6	1.44	5.42	0.12	24.88	0.48	6.4	263.42	17.38	284.33	8.72
S_7	1.33	5.94	0.24	32.32	0.35	12.8	276.12	26.69	310.28	6.02
S_8	1.28	5.75	0.13	51.6	0.54	13.7	302.56	24.52	226.56	7.83
S_9	1.35	6.45	0.22	23.6	0.34	11.5	254.26	33.05	325.4	7.28
S_{10}	1.41	5.14	0.08	26.32	0.68	8.3	335.4	15.12	219.58	9.61
Range	1.28–1.44	5.14–6.59	0.08–0.26	22.88–51.60	0.34–0.73	6.40–13.70	254.26–357.21	11.56–36.53	219.58–325.40	10.21–21.25
Mean	1.37	5.92	0.17	32.37	0.51	10.18	304.92	25.21	273.53	8.08
SD	0.05	0.46	0.06	10.11	0.15	2.87	36.39	8.85	35.85	1.11

(0.76 %) in soils of Md. Bazar block. The CEC of the soils under investigation varied from 5.40 to 19.22 [C mol (P+) kg^{-1}] with an average of 9.39 [C mol (P+) kg^{-1}]. Among the macronutrients analyzed, available N, P_2O_5 and K_2O content (kg ha^{-1}) varied from 254.26 to 421.20, 10.31 to 41.22 and 131.25 to 325.42 respectively. Soils of all the five blocks showed deficiency in available sulphur content (< 10 mg kg^{-1}). Similar observationswasalso reported by Hembram et al, (2012) and Ghosh et al. (2005).

3.2. Extractable Micronutrients

The range and means of the extractable micronutrients cation under five different blocks were presented inTable 7-11. The extractable Zn- Mehlich 3, Zn- HCl, Zn-AB-DTPA and Zn-DTPA values of study area ranged from 1.45-2.88, 0.86-2.56, 0.55-1.98 and 0.41-1.76 mg

Table 5: Physico-chemical properties of lateritic soils of Md. Bazar block of Birbhum District, West Bengal

Sample	BD ($g\ cc^{-1}$)	pH	EC ($ds\ m^{-1}$)	Clay (%)	OC (%)	CEC [C mol (P+) kg^{-1}]	N ($kg\ ha^{-1}$)	P_2O_5 ($kg\ ha^{-1}$)	K_2O ($kg\ ha^{-1}$)	S ($mg\ kg^{-1}$)
S_1	1.35	4.74	0.07	50.88	0.73	11.5	342.56	11.25	142.53	4.32
S_2	1.48	5.05	0.14	31.6	0.52	5.8	230.08	23.41	185.34	7.45
S_3	1.44	4.22	0.05	31.44	0.76	6.5	335.29	12.52	153.27	3.72
S_4	1.38	5.59	0.16	31.6	0.68	6.1	221.52	26.37	254.62	6.15
S_5	1.54	4.84	0.1	25.6	0.71	5.4	340.18	13.85	163.24	5.72
S_6	1.36	4.42	0.04	40.88	0.54	8.6	251.15	11.52	148.62	4.34
S_7	1.51	5.14	0.15	26.32	0.58	7.2	276.12	25.64	210.52	6.19
S_8	1.46	4.65	0.03	25.6	0.67	10.3	264.53	22.14	205.73	4.46
S_9	1.39	5.45	0.17	25.6	0.55	6.7	223.85	24.28	276.15	4.61
S_{10}	1.45	4.64	0.11	38.88	0.74	6.1	289.64	20.13	189.64	5.63
Range	1.35–1.54	4.22–5.59	0.03–0.17	25.60–50.88	0.52–0.76	5.40–11.50	221.52–342.56	11.25–26.37	142.53–276.15	3.72–7.45
Mean	1.44	4.87	0.10	32.84	0.65	7.42	277.49	19.11	192.97	5.26
SD	0.06	0.44	0.05	8.38	0.09	2.05	48.04	6.16	45.01	1.15

Table 6: Physico-chemical properties of lateritic soils ofBolpur block of Birbhum District, West Bengal

Sample	BD ($g\ cc^{-1}$)	pH	EC ($ds\ m^{-1}$)	Clay (%)	OC (%)	CEC [C mol (P+) kg^{-1}]	N ($kg\ ha^{-1}$)	P_2O_5 ($kg\ ha^{-1}$)	K_2O ($kg\ ha^{-1}$)	S ($mg\ kg^{-1}$)
S_1	1.43	4.12	0.04	12.72	0.39	6.9	221.53	12.38	189.34	7.55
S_2	1.28	4.49	0.07	24.88	0.46	9.9	283.6	14.57	201.6	8.68
S_3	1.30	5.22	0.12	25.6	0.54	11.1	320.15	21.54	312.14	7.95
S_4	1.22	5.14	0.11	40.88	0.57	17.5	211.23	18.24	287.11	9.38
S_5	1.38	5.09	0.15	26.32	0.43	9.8	240.42	16.24	325.42	6.95
S_6	1.37	5.61	0.15	25.6	0.59	10.8	412.1	25.18	249.68	8.57
S_7	1.34	4.57	0.07	24.16	0.32	8.5	213.27	17.66	221.25	6.42
S_8	1.27	5.42	0.09	38.88	0.51	11.0	408.74	22.73	295.35	6.86
S_9	1.15	4.48	0.06	48.16	0.67	19.2	213.44	10.31	142.64	8.69
S_{10}	1.44	5.54	0.21	14.88	0.35	7.2	421.2	25.24	322.14	7.84
Range	1.15–1.44	4.12–5.61	0.04–0.21	12.72–48.16	0.32–0.67	6.90–19.22	211.23–421.20	10.31–25.24	142.64–325.42	6.42–9.38
Mean	1.32	4.97	0.11	28.21	0.48	11.19	294.57	18.41	254.67	7.89
SD	0.09	0.52	0.05	11.23	0.11	4.08	89.48	5.20	63.55	0.95

kg^{-1} with mean values of 2.17, 1.68, 1.19 and 0.94 mg kg^{-1}. The Mehlich 3 extracted more extractable Zn from the soils than any other extractants. This could be due to the extractant's double acid effect and high pH, as well as the presence of the NH_4^+ ion, which allows Mehlich 3 to displace exchangeable cations (Fernandez-Marcos et al., 1998). Abreu et al. (2004) and Da Fonseca et al. (2010) also observed that Mehlich 3 solution extracted more Zn than HCl and DTPA extractants. HCl ranked second in the extraction of Zn. The extractants ranked as follows: Mehlich 3>HCl>AB-DTPA>DTPA. These findings are in agreement with observations of Pradhan et al. (2015). The average values of extractable Fe content of the soils under the investigation observed 49.57, 45.46, 39.67 and 34.89 mg kg^{-1} by extractants,Mehlich 3,HCl, AB-DTPA and DTPA respectively. Higher mean value of extractable Fe content (47.36 mg kg^{-1}) was observed in soils of Dubrajpur block. It may due to higher clay content of these soils. The lowest

Table 7: Status of extractable micronutrients cation in soils of Dubrajpur block of Birbhum District, West Bengal

Sample	Extractable Zn (mg kg^{-1})				Extractable Fe(mg kg^{-1})			
	Mehlich-3	HCl	AB-DTPA	DTPA	Mehlich-3	HCl	AB-DTPA	DTPA
S_1	1.78	1.23	0.96	0.85	56.47	58.14	52.42	48.42
S_2	1.56	1.02	0.87	0.74	58.24	61.26	54.26	52.14
S_3	1.84	1.12	0.55	0.41	50.14	46.21	41.06	34.26
S_4	1.64	0.97	0.61	0.52	52.31	44.51	39.85	30.54
S_5	1.45	1.03	0.89	0.78	50.14	50.29	46.84	44.81
S_6	1.83	1.23	0.94	0.64	54.31	49.37	46.21	40.52
S_7	2.01	1.14	0.76	0.51	50.12	46.13	40.62	35.71
S_8	1.86	1.25	0.92	0.89	48.76	48.92	45.57	37.21
S_9	1.67	0.86	0.67	0.42	48.54	44.28	38.16	31.04
S_{10}	1.74	1.05	0.77	0.51	54.31	59.37	54.61	48.41
Range	1.45–2.01	0.86–1.25	0.55–0.96	0.41–0.89	48.54–58.24	44.28–61.26	38.16–54.61	30.54–52.14
Mean	1.74	1.09	0.79	0.63	52.33	50.85	45.96	40.31
SD	0.16	0.13	0.15	0.18	3.36	6.39	6.12	7.75

Table 7: Continue...

Sample	Extractable Mn (mg kg^{-1})				Extractable Cu (mg kg^{-1})			
	Mehlich-3	HCl	AB-DTPA	DTPA	Mehlich-3	HCl	AB-DTPA	DTPA
S_1	54.12	48.21	44.64	40.25	2.04	1.71	1.45	1.32
S_2	48.35	45.3	42.82	42.01	2.15	1.86	1.62	1.46
S_3	37.11	33.95	28.15	20.31	2.31	1.76	1.49	1.24
S_4	36.71	34.18	28.27	18.67	2.18	1.89	1.58	1.4
S_5	46.71	44.13	42.94	39.22	2.71	2.46	2.31	1.95
S_6	43.62	37.81	30.14	28.35	2.54	2.03	1.76	1.59
S_7	32.67	24.62	19.34	17.25	2.39	1.77	1.56	1.24
S_8	44.82	42.37	38.42	32.62	2.61	1.86	1.68	1.53
S_9	47.62	45.63	41.37	37.1	2.45	1.94	1.64	1.08
S_{10}	53.72	51.64	45.84	41.28	2.63	1.88	1.72	1.39
Range	32.67–54.12	24.62–51.64	19.34–45.84	17.25–42.01	2.04–2.71	1.71–2.46	1.45– 2.31	1.08–1.95
Mean	44.55	40.78	36.19	31.71	2.4	1.92	1.68	1.42
SD	7.17	8.1	9.03	9.87	0.23	0.21	0.24	0.24

value (39.13 mg kg^{-1}) observed in soils of Illambazar block, which may due to higher pH of the areas. In case of Melich 3-Mn content, it ranged from 32.67 to 54.12 mg $kg^{-1}$with an average value of 44.55 mg kg^{-1}in soils of Dubrajpur block, 45.97 to 61.35 mg kg^{-1} with a mean value of 53.90 mg kg^{-1}in soils of Sainthia block, 33.18 to 52.60 mg kg^{-1} with a mean value of 42.68 mg kg^{-1}in soils of Illambazar block, 40.28 to 57.34 mg kg^{-1} with a mean value of 49.80 mg kg^{-1} in soils of Md. Bazar block and 22.17 to 46.28mg $kg^{-1}$with a mean value of 34.09 mg kg^{-1}in soils of Bolpur block indicating its sufficiency in these soils. Whereas the average values of DTPA-Mn varied 31.71, 31.06, 27.01, 31.25 and 22.97 mg kg^{-1}respectively. The relative high content of Mn in these soils could be due to the soils derived from basaltic parent material which contained higher ferro-magnessiume minerals. The amount of extractable Mn varied remarkably depending on and extractants used and the parent material from which the soils are derived (Yusuf et al., 2005).Similar results were reported by Hundal et al. (2006).The extractable Cu content of the study area showed similar trend as other micronutrients, Melich 3 extracted higher amount of Cu from the same soils as compared to other extractants like

Table 8: Status of extractable micronutrients cation in soils of Sainthia block of Birbhum District, West Bengal

Sample	Extractable Zn (mg kg^{-1})				Extractable Fe(mg kg^{-1})			
	Mehlich-3	HCl	AB-DTPA	DTPA	Mehlich-3	HCl	AB-DTPA	DTPA
S_1	2.04	1.56	1.23	0.96	46.28	35.52	31.5	26.12
S_2	1.68	1.48	1.14	1.03	45.31	41.23	36.41	32.84
S_3	1.76	1.25	0.76	0.49	42.37	35.17	28.4	23.1
S_4	2.46	2.08	1.85	1.6	55.94	50.24	45.68	42.98
S_5	2.58	2.14	0.95	0.69	51.02	45.28	39.74	33.24
S_6	2.37	1.98	0.71	0.45	52.37	46.37	30.98	27.26
S_7	2.09	1.68	1.21	0.96	54.96	52.31	46.75	44.98
S_8	2.14	1.75	1.1	0.64	39.41	35.43	28.46	25.34
S_9	2.46	1.83	1.42	1.16	51.32	45.61	41.32	37.2
S_{10}	2.52	2.31	1.93	1.34	56.47	52.12	44.26	40.36
Range	1.68–2.58	1.25–2.31	0.71–1.93	0.45–1.6	39.41–56.47	35.17–52.31	28.4–46.75	23.1–44.98
Mean	2.21	1.81	1.23	0.93	49.55	43.93	37.35	33.34
SD	0.32	0.33	0.41	0.37	5.91	6.79	7.16	7.82

Table 8: Continue...

Sample	Extractable Mn (mg kg^{-1})				Extractable Cu (mg kg^{-1})			
	Mehlich-3	HCl	AB-DTPA	DTPA	Mehlich-3	HCl	AB-DTPA	DTPA
S_1	45.97	36.74	27.31	23.16	3.05	2.76	2.51	2.31
S_2	48.75	42.38	36.52	30.13	2.53	2.13	1.86	1.43
S_3	52.97	46.37	30.24	26.8	3.12	2.86	2.76	2.55
S_4	54.16	50.16	45.67	40.28	2.87	2.64	2.02	1.5
S_5	56.37	44.92	38.42	26.24	2.64	1.97	1.64	1.25
S_6	52.17	46.37	43.19	30.15	3.21	2.89	2.76	2.42
S_7	61.35	56.75	48.74	42.13	2.89	2.64	1.86	1.42
S_8	58.43	47.29	34.29	25.14	3.14	2.88	2.59	2.06
S_9	50.14	43.51	38.37	30.32	2.95	2.46	1.95	1.1
S_{10}	58.64	52.31	42.34	36.24	3.24	3.02	2.71	2.48
Range	45.97–61.35	36.74–56.75	27.31–48.74	23.16–42.13	2.53–3.24	1.97–3.02	1.64–2.76	1.1–2.55
Mean	53.90	46.68	38.51	31.06	2.96	2.63	2.27	1.85
SD	4.85	5.54	6.73	6.46	0.24	0.34	0.44	0.57

HCl, AB-DTPA and DTPA. Similar findings also observed by Padhan et al. 2022. The low extractability of the DTPA extractant may due to disruption of metal-chelate equilibria in acidic soils.A dynamic equilibrium was noticed among the extractable forms of all the cationic micronutrients, implying that they were able to extract the said micronutrients from remarkably similar pools. For all cationic micronutrients, the overall extractability of the different extractants, regardless of experimental site, can be ranked as follows: Mehlich 3>HCl>AB-DTPA>DTPA.

3.3. Relationships among the Extractants

Table 12–15 illustrated the relationships among the micronutrients cation extractants assessed in lateritic soils of Birbhum district. Table 12 showed that the extractable Zn extracted from the soil by Mehlich3 has high and significant correlation (p<0.01) with the contents extracted by HCl (r=0.943**), AB-DTPA (r= 0.719**) and DTPA (r= 0.628**). These results indicate that regardless of the nature of the extractant, the extraction capacity of all methods studied is similar for estimating Zn contents in under the study area. Similarly, a significant and highly positive correlation noted among the extractable Fe content

Table 9: Status of extractable micronutrients cation in soils of Illambazar block of Birbhum District, West Bengal

Sample	Extractable Zn (mg kg^{-1})				Extractable Fe(mg kg^{-1})			
	Mehlich-3	HCl	AB-DTPA	DTPA	Mehlich-3	HCl	AB-DTPA	DTPA
S_1	1.75	1.26	1.15	1.05	49.37	42.31	35.24	34.53
S_2	1.62	1.32	0.95	0.68	44.26	36.84	26.75	24.56
S_3	1.53	1.05	0.74	0.45	48.67	43.15	34.97	35.21
S_4	1.72	1.13	0.88	0.79	40.29	35.19	28.41	28.4
S_5	2.03	1.68	1.38	1.12	52.37	46.38	41.25	37.85
S_6	2.14	1.75	1.31	1.18	50.17	42.37	38.34	40.23
S_7	1.53	1.05	0.89	0.64	50.16	44.39	37.15	34.61
S_8	1.67	1.32	1.05	0.85	45.38	38.16	32.54	30.56
S_9	1.85	1.02	0.64	0.46	44.39	35.19	30.05	27.11
S_{10}	1.93	1.53	1.13	0.96	52.04	46.37	41.35	38.58
Range	1.53–2.14	1.02–1.75	0.64–1.38	0.45–1.18	40.29–52.37	35.19–46.38	26.75–41.35	24.56–40.23
Mean	1.78	1.31	1.01	0.82	47.71	41.04	34.61	33.16
SD	0.21	0.27	0.24	0.26	3.94	4.35	5.12	5.27

Table 9: Continue...

Sample	Extractable Mn (mg kg^{-1})				Extractable Cu (mg kg^{-1})			
	Mehlich-3	HCl	AB-DTPA	DTPA	Mehlich-3	HCl	AB-DTPA	DTPA
S_1	43.27	42.38	32.14	28.26	2.75	2.28	1.58	1.32
S_2	33.18	35.16	24.36	18.63	2.84	2.16	1.69	1.43
S_3	39.37	37.84	24.98	21.4	2.96	2.37	1.75	1.54
S_4	35.78	35.61	27.37	19.25	2.76	2.59	2.03	1.76
S_5	44.37	48.19	42.1	34.52	2.97	2.67	1.98	1.12
S_6	52.16	46.67	38.31	30.27	2.88	2.49	1.84	1.35
S_7	50.18	44.28	38.46	32.52	3.02	2.76	2.13	1.68
S_8	41.05	42.16	34.68	27.13	2.93	2.58	2.14	1.44
S_9	37.15	36.39	27.64	22.53	2.81	2.6.3	2.3	1.52
S_{10}	50.27	46.85	42.28	35.63	2.79	2.34	1.95	1.23
Range	33.18–52.16	35.16–48.19	24.36–42.28	18.63–35.63	2.75–3.02	2.16–2.76	1.58–2.30	1.12–1.76
Mean	42.68	41.55	33.23	27.01	2.87	2.47	1.94	1.44
SD	6.57	4.98	6.91	6.28	0.10	0.20	0.22	0.20

Table 10: Status of extractable micronutrients cation in soils of Md. Bazar block of Birbhum District, West Bengal

Sample	Extractable Zn (mg kg^{-1})				Extractable Fe(mg kg^{-1})			
	Mehlich-3	HCl	AB-DTPA	DTPA	Mehlich-3	HCl	AB-DTPA	DTPA
S_1	2.84	2.31	1.75	1.58	54.24	48.34	39.41	34.21
S_2	2.16	1.89	1.36	1.15	45.16	40.28	33.25	24.56
S_3	2.56	2.05	1.89	1.76	46.94	41.84	35.29	30.14
S_4	2.34	1.74	1.26	0.92	46.38	40.09	33.58	26.45
S_5	2.84	2.35	1.82	1.68	53.61	46.74	40.28	35.86
S_6	2.88	2.56	1.98	1.34	57.66	50.82	45.18	37.28

Sample	Extractable Zn (mg kg^{-1})				Extractable Fe(mg kg^{-1})			
	Mehlich-3	HCl	AB-DTPA	DTPA	Mehlich-3	HCl	AB-DTPA	DTPA
S_7	2.19	1.68	1.32	1.05	54.97	46.77	35.94	28.16
S_8	2.56	1.93	1.69	1.46	51.16	44.51	40.16	34.52
S_9	2.14	1.67	1.28	0.97	42.85	38.95	28.64	23.14
S_{10}	2.43	1.9	1.76	1.42	52.17	46.37	43.19	38.15
Range	2.14–2.88	1.67–2.56	1.26–1.98	0.92–1.76	42.85–57.66	38.95–50.82	28.64–45.18	23.14–38.15
Mean	2.49	2.01	1.61	1.33	50.51	44.47	37.49	31.25
SD	0.29	0.31	0.28	0.30	4.89	3.99	5.04	5.47

Table 10: Continue...

Sample	Extractable Mn (mg kg^{-1})				Extractable Cu (mg kg^{-1})			
	Mehlich-3	HCl	AB-DTPA	DTPA	Mehlich-3	HCl	AB-DTPA	DTPA
S_1	52.25	45.36	38.15	34.21	2.45	1.96	1.78	1.65
S_2	43.38	36.45	30.17	24.56	3.11	3.05	2.82	2.54
S_3	50.27	43.18	36.67	30.14	3.08	2.76	2.59	2.04
S_4	42.23	38.65	31.28	26.45	2.88	2.57	2.06	1.85
S_5	53.14	48.33	42.11	35.86	2.91	2.67	2.34	1.75
S_6	57.34	50.26	44.05	37.28	3.11	2.88	2.67	2.51
S_7	50.46	43.17	36.88	28.16	3.28	3.15	2.84	2.65
S_8	54.97	46.95	41.19	34.52	3.37	3.02	2.75	2.34
S_9	40.28	35.11	29.48	23.14	3.14	2.86	2.68	2.54
S_{10}	53.64	47.84	43.52	38.15	2.86	2.73	2.33	1.86
Range	40.28–57.34	35.11–50.26	29.48–44.05	23.14–38.15	2.45–3.37	1.96–3.15	1.78–2.84	1.78–2.84
Mean	49.80	43.53	37.35	31.25	3.02	2.77	2.49	2.17
SD	5.82	5.24	5.50	5.47	0.26	0.34	0.35	0.38

Table 11: Status of extractable micronutrients cation in soils of Bolpur block of Birbhum District, West Bengal

Sample	Extractable Zn (mg kg^{-1})				Extractable Fe(mg kg^{-1})			
	Mehlich-3	HCl	AB-DTPA	DTPA	Mehlich-3	HCl	AB-DTPA	DTPA
S_1	2.88	2.42	1.63	1.33	54.89	54.21	48.62	43.28
S_2	2.67	2.11	1.44	1.23	48.32	50.11	45.14	39.41
S_3	2.76	2.31	1.05	0.86	47.18	45.64	40.31	34.19
S_4	2.45	2.08	0.88	0.67	46.25	46.38	41.35	31.28
S_5	2.28	2.15	1.1	0.73	42.85	44.59	39.85	32.55
S_6	2.75	2.27	1.42	0.94	40.19	36.25	35.54	33.24
S_7	2.64	2.54	1.36	0.82	47.68	48.24	46.38	41.61
S_8	2.34	1.98	1.44	1.12	45.95	44.22	39.42	32.76
S_9	2.77	2.35	1.62	1.30	51.11	51.98	48.31	40.08
S_{10}	2.63	1.88	0.98	0.78	52.84	48.37	44.52	35.34
Range	2.28–2.88	1.88–2.54	0.88–1.63	0.67–1.33	40.19–54.89	36.25–54.21	35.54–48.62	31.28–43.28
Mean	2.62	2.21	1.29	0.98	47.73	47.00	42.94	36.37
SD	0.20	0.21	0.27	0.25	4.42	4.96	4.30	4.31

Table 11: Continue...

Sample	Extractable Mn (mg kg^{-1})				Extractable Cu (mg kg^{-1})			
	Mehlich-3	HCl	AB-DTPA	DTPA	Mehlich-3	HCl	AB-DTPA	DTPA
S_1	44.25	41.56	36.45	37.25	2.89	2.65	2.45	2.21
S_2	40.13	35.12	29.15	28.63	2.76	2.35	1.97	1.76
S_3	26.97	24.64	18.24	17.48	2.5	2.05	1.54	1.37
S_4	22.17	19.37	14.12	14.25	2.34	1.86	1.62	1.78
S_5	33.56	28.39	20.85	19.21	2.94	2.64	2.04	1.86
S_6	27.13	20.05	15.99	14.2	2.38	1.89	1.64	1.28
S_7	36.98	33.21	30.25	33.44	3.02	2.71	2.44	2.19
S_8	33.24	25.95	17.22	15.66	2.69	1.83	1.52	1.13
S_9	46.28	45.94	41.31	36.52	3.05	2.84	2.41	2.04
S_{10}	30.15	22.43	18.34	13.07	2.41	1.77	1.34	1.02
Range	22.17–46.28	19.37–45.94	14.12–41.31	13.07–37.25	2.34–3.05	1.77–2.84	1.34–2.45	1.02–2.21
Mean	34.09	29.67	24.19	22.97	2.70	2.26	1.90	1.66
SD	7.85	9.07	9.44	9.88	0.27	0.42	0.42	0.44

Table 12: Relationships among the extractants in extracting zinc (Zn) cation in soils ofBirbhum District, West Bengal

Extractants	Melich 3	HCl	AB-DTPA	DTPA
Melich 3	1			
HCl	.943**	1		
AB-DTPA	.719**	.763**	1	
DTPA	.628**	.647**	.945**	1

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

Table 13: Relationships among the extractants in extracting iron (Fe) cation in soils ofBirbhum District, West Bengal

Extractants	Melich 3	HCl	AB-DTPA	DTPA
Melich 3	1			
HCl	.834**	1		
AB-DTPA	.733**	.937**	1	
DTPA	.702**	.870**	.925**	1

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

Table 14: Relationships among the extractants in extracting manganese (Mn) cation in soils of Birbhum District, West Bengal

Extractants	Melich 3	HCl	AB-DTPA	DTPA
Melich 3	1			
HCl	.941**	1		
AB-DTPA	.889**	.951**	1	
DTPA	.791**	.868**	.937**	1

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

Table 15: Relationships among the extractants in extracting copper (Cu) cation in soils ofBirbhum District, West Bengal

Extractants	Melich 3	HCl	AB-DTPA	DTPA
Melich 3	1			
HCl	.719**	1		
AB-DTPA	.851**	.667**	1	
DTPA	.690**	.642**	.900**	1

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

extracted by different extractants. These indicated that all the extractants are extractable Fe extracted from similar pools which are highly changeable in chemical, physical and mineralogical properties. A high and significant positive correlation noted between Melich 3-Mn and HCl-Mn (r=0.941**) as reported by Vocasek, and Friedericks (1994). Among the different extracted used for Cu estimation highest correlation observed between AB-DTPA-Cu and DTP-Cu (r= 0.900**). Similar observation also reported by Shittu and Ilori (2016)

4. CONCLUSION

The suitability of cationic micronutrient extraction by different extractants was primarily influenced by the soils' physicochemical properties, including pH, clay content, and organic matter, implying the importance of selecting different extractants for different soils based on their physicochemical properties. Among the major extractants tested, Melich 3 outperformed over all others. The order of extractability was Mehlich 3>HCl>AB-DTPA>DTPA.Melich 3 may be substituted for the analysis of cationic micronutrient status in soils from rice-based cropping systems in West Bengal's lateritic belt.

5. FURTHER RESEARCH

Further studies are required to investigate plant uptake in relation to these extraction methods, which may increase their effectiveness in this study.

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7. REFERENCES

Abreu, C.A., vanRaij, B., Abreu, M.F., Santos, W.R., Andrade, J.C., 2004. Efficiency of multinutrient extractants for the determination of available copper in soils. Communications in Soil Science and Plant Analysis 27, 763–771.

Agrawal, R., Kumar, B., Priyanka, K., Narayan, C., Shukla, K., Sarkar, J., 2016. Micronutrient fractionation in coal mine-affected agricultural soils, India. Bulletin of Environmental Contamination and Toxicology 96(4), 449–457.

Athokpam, H.S., Zimik, V.S., Chongtham, N., Devi, K.N., Singh, N.B., Watham, L., Sharma, P.T., Athokpam,H., 2016. Profile distribution of micronutrient cations in citrus orchard of Ukhrul district, Manipur (India). International Journalof Agriculture, Environment and Biotechnology 9(4), 691–697.

Bailey, R.L., West Jr., K.P., Black, R.E., 2015. The epidemiology of global micronutrient deficiencies. Annals of Nutrition and Metabolism 66 (2), 22–33.

Baldantoni, D., Saviello, G., Alfani, A., 2019. Nutrients and nonessential elements in edible crops following long-term mineral and compost fertilization of a Mediterranean agricultural soil. Environmental Science and Pollution Research 26, 35353–35364. doi: 10.1007/s11356-018-3353-8.

Barker, A.V., Pilbeam, D.J., 2015. Handbook of Plant Nutrition (2nd Edn.). CRC Press, London, 678.

Bell, R.W., Dell, B., 2008. Micronutrients for Sustainable Food, Feed, Fibreand Bioenergy Production. International Fertilizer Industry Association (IFA) Paris, France, 80–88.

Black, C.A., 1965. Methods of Soil Analysis (Part-II). Agronomy Series. No. 9, American Society Agronomy, Inc., Madison, 45–87.

Bouyoucos, G.J., 1927. The hydrometer as a new method for the mechanical analysis of soils. Soil Science 23(5), 343–354.

Bray, R.H., Kurtz, L.T., 1945. Determination of total, organic, and available forms of phosphorus in soils. Soil Science 59(1), 39–46.

Cakmak, I., Kutman, U.B., 2018. Agronomic biofortification of cereals with zinc: a review. The European Journal of Soil Science 69, 172–180.DOI https://doi.org/10.1111/ejss.12437.

De-Regil, L.M., Suchdev, P.S., Vist, G.E., Walleser, S., Pena Rosas, J.P., 2013. Home fortification of foods with multiple micronutrient powders for health and nutrition in children under two years of age. Evidence Based Child Health: A Cochrane Review Journal 8 (1), 112–201.

Dhaliwal, S.S., Naresh, R.K., Mandal, A., Singh, R., Dhaliwal, M.K., 2019. Dynamics and transformations of micronutrients in agricultural soils as influenced by organic matter build-up: A review. Environmental and Sustainability Indicators 1, 100007.

Fageria, N.K., Baligar, V.C., Clark, R.B., 2002. Micronutrients in Crop Production. Advances in Agronomy 77, 185–268. DOI http://dx.doi.org/10.1016/S0065-2113(02)77015-6.

Fernandez-Marcos M.L., Alvarez E., Monterroso C., 1998. Aluminium and iron estimated by Mehlich-3 extractant in mine soils in Galicia, northwest Spain. Communications in Soil Science and Plant Analysis 29, 599–612.

Fonseca, A.F.D., Caires, E.F., Barth, G., 2010. Extraction methods and availability of micronutrients for wheat under a no-till system with a surface application of lime. Scientia Agricola 67, 60–70.

Gao, S., Yau, R., Chan, F., 2008. Effect of Cu on growth, antioxidant Enzymes and ammonia lyase activities in *Jatropha curcas* seedling. Plant and Soil Environment 54, 11.

Ghosh, G.K., Chattopadhyay, G.N., Chattopadhyay, S., 2005. Availability and forms of sulphur in red and lateritic soils of Birbhum district of West Bengal. Indian Journal of Agricultural Sciences 75(6), 358–360.

Gomez, K.A., Gomez, A.A., 1984. Statistical Procedures for Agricultural Research. John Wiley & Sons.

Gupta, U.C., Kening, W.U., Liang, S., 2008. Micronutrients in soils, crops, and livestock. Earth Science Frontiers 15(5), 110–125. DOI http://dx.doi.org/10.1016/S1872-5791(09)60003-8.

Hegde, R., Kumar, M., Niranjana, M.B., Seema, K.V., Dhanorkar, B.A., 2021. Study on the soil fertility and mapping in ramasamudram-1 microwatershed of Yadgir Taluk and district of Karnataka, India. International Journal of Bio-resource and Stress Management 12(4), 348–360. DOI https://doi.org/10.23910/1.2021.2262.

Hembram, S., Mukhopadhyay, P., Patra, P. K., 2012. Distribution of available S in some soil series of West Bengal growing rice and pulses. International Journal of Bio-resource and Stress Management 3(3), 332–335.

Hundal, H.S., Kumar, R., Singh, D., Manchanda, J.S., 2006. Available nutrient and heavy metal status of soils of Punjab, North-west India. Journal of the Indian Society of Soil Science 54(1), 50–56.

Ibrahim, A.K., Abubakar, B., 2013. Extractable micronutrients status with other soil properties in Jangargari, Yamaltu-Deba Local Government Area, Gombe state. Asian Journal of Agricultural and Food Sciences 1(5), 217–221.

Jackson, M.L., 1973. Soil Chemical Analysis. Prentice Hall of India Pvt. Ltd., New Delhi, India, 151–154.

Jan, A.U., Hadi, F., Ditta, A., Suleman, M., Ullah, M., 2022. Zinc-induced anti-oxidative defense and osmotic adjustments to enhance drought stress tolerance in sunflower (*Helianthus annuus* L.). Environmental and Experimental Botany, 193, 104682.

Jones, J. B., 1998. Soil test methods: past, present, and future use of soil extractants. Communications in Soil Science and Plant Analysis 29(11–14), 1543–1552.

Katyal, J.C., 2018. Micronutrients in Indian Agriculture. Indian Journal of Fertilizers 14(4), 12–26.

Korzeniowska, J., Stanislawska-Glubiak, E., 2013. A comparison of the suitability of several methods to estimate the bioavailability of elements in soils to plants. Fresenius Environmental Bulletin 22(4), 943–948.

Lindsay, W.L., Norvell, W., 1978. Development of a DTPA soil test for zinc, iron, manganese, and copper. Soil Science Society of America Journal 42(3), 421–428.

Mehlich, A., 1984. Mehlich 3 soil test extractant: A modification of Mehlich 2 extractant. Communications in Soil Science and Plant Analysis 15(12), 1409–1416.

Monreal, C.M., DeRosa, M., Mallubhotla, S.C., Bindraban, P.S., Dimkpa, C., 2016. Nanotechnologies for increasing the crop use efficiency of fertilizer-micronutrients. Biology and Fertility of Soils 52, 423–437.

Muhar, G.R., Datta, N.P., Shankara, S.N., Dever, F., Lecy, V.K., Donahue, R.R.,1963. Soil testing in India. USDA Mission to India.

Norvell, W.A., 1984. Comparison of chelating agents as extractants for metals in diverse soil materials. Soil Science Society of America Journal 48(6), 1285–1292.

Osiname, O.A., Schulte, E.E., Corey, R.B., 1973. Soil tests for available copper and zinc in soils of Western Nigeria. Journal of the Science of Food and Agriculture 24(11), 1341–1349.

Padhan, D., Shivaswamy, M.B., Sobhana, V., Ravindra, C.M., Babulal, 2022. Selection of suitable extractants for the determination of available copper in soils of Mulberry Garden. Chemical Science Review and Letters 11(42), 276–283. DOI 10.37273/chesci.cs205303439.

Pradhan, A.K., Beura, K.S., Das, R., Padhan, D., Hazra, G.C., Mandal, B., De, N., Mishra, V.N., Polara, K.B., Sharma, S., 2015. Evaluation of extractability of different extractants for zinc and copper in soils under long-term fertilization. Plant, Soil and Environment 61(5), 227–233.

Ray, S.K., Banik, G.C., 2016. Available micronutrient status in relation to soil properties in some villages under four agro-climatic features of West Bengal. Journal of the Indian Society of Soil Science 64(2), 169–175.

Rengel, Z., 2007. Cycling of micronutrients in terrestrial ecosystems. In: Marschner, P., Rengel, Z. (Eds.), Nutrient Cycling in Terrestrial Ecosystems. Springer, 93–121. DOI http://dx.doi.org/10.1007/978-3-540-68027-7_4.

Rengel, Z., 2015. Availability of Mn, Zn and Fe in the rhizosphere. Journal of Soil Science and Plant Nutrition 15(2), 397–409.

Rutkowska, B., Szulc, W., Sosulski, T., Stepien, W., 2014. Soil micronutrient availability to crops affected by long-term inorganic and organic fertilizer applications. Plant and Soil Environment 60, 198–203.

Samreen, T., Shah, H.U., Ullah, S., Javid, M., 2017. Zinc effect on growth rate, chlorophyll, protein and mineral contents of hydroponically grown mungbeans plant (*Vigna radiata*). Arabian Journal of Chemistry 10 (2), 1802–1807.

Sarwar, N., Malhi, S.S., Zia, M.H., Naeem, A., Bibi, S., Farid, G., 2010. Role of mineral nutrition in minimizing cadmium accumulation by plants. Journal of the Science of Food and Agriculture 90(6), 925–937.

Schollenberger, C.J., Simon, R.H., 1945. Determination of exchange capacity and exchangeable bases in soil ammonium acetate method. Soil Science 59, 13–24.

Shambhavi, S., Kumar, R., Sharma, S.P., Verma, G., Sharma, S.K., Sharma, R.P., 2018. Effect of 36 years of continuous cropping and fertilization on productivity, micro and secondary nutrient status and

uptake by maize-wheat cropping system in western Himalayas. International Journal of Bio-resource and Stress Management 9(2), 197–202.
Shi, J., Wu, Q., Zheng, C., Yang, J., 2018. The interaction between particulate organic matter and Copper, Zinc in paddy soil. Environmental Pollution 243, 1394–1402. DOI https://doi.org/10.1016/j.envpol.2018.09.085.
Shittu, O., Ilori, A., 2016. Evaluation of universal extractants for determination of selected micronutrients on soils developed over charnockite in Ekiti state. Journal of Biology, Agriculture and Healthcare 6, 58–68.
Shittu, O.S., Ogunwale, J.A., Ayodele, O.J., 2010. Total and extractable iron and manganese in soils developed on charnockite in Ekiti state, Nigeria. International Journal of water and soil Resources Research 1(1–3), 83–93.
Shukla, A.K., Malik, R.S., Tiwari, P.K., Prakash, C., Behera, S.K., Yadav, H., Narwal, R.P., 2015. Status of micronutrient deficiencies in soils of Haryana. Indian Journal of Fertilizer 1, 16–27.
Singh, P., Patidar, D.K., Prajapat, O.M., 2017. Role of foliar application of micronutrients (B, Zn and Fe) in vegetables. International Journal of Farm Sciences 7(2), 15–21.
Soltanpour, P.N., Schwab, A.P., 1977. A new soil test for simultaneous extraction of macro-and micro-nutrients in alkaline soils. Communications in Soil Science and Plant Analysis 8(3), 195–207.
Srinivasan, R., Singh, S.K., Nayak, D.C., Dharumarajan, S., 2017. Assessment of soil properties and nutrients status in three horticultural land use system of coastal Odisha, India. International Journal of Bio-resource and Stress Management 8(1), 033–040.
Subbiah, B.V., Asija, G.L., 1956. A rapid procedure for the determination of available nitrogen in soils. Current Science 25(8), 259–260.
Thapa, S., Bhandari, A., Ghimire, R., Xue, Q., Kidwaro, F., Ghatrehsamani, S., Maharjan, B., Goodwin, M., 2021. Managing micronutrients for improving soil fertility, health, and soybean yield. Sustainability, 13(21), 11766.
Tisdale, S.L., Nelson, W.L., Beaton, J.D., 1985. Soil Fertility and Fertilizers. Collier Macmillan Publishers, London, UK.
Van Raij, B., 1998. Bioavailable tests: Alternatives to standard soil extractions. Communications in Soil Science and Plant Analysis 29(11–14), 1553–1570.
Vocasek, F.F., Friedericks, J.B., 1994. Soil micronutrient extraction by mehlich-3 compared to $CaCl_2$-DTPA.Communications in Soil Science and Plant Analysis 25(9–10), 1583–1593. DOI 10.1080/00103629409369137.
Voortman, R., Bindraban, P.S., 2015. Beyond N and P: toward a Land Resource Ecology Perspective and Impactful Fertilizer Interventions in Sub-saharan Africa. VFRC Report 2015/1. Virtual Fertilizer Research Center, Washington DC, USA, 49.
Walkley, A., Black, I.A., 1934. An examination of the Degtjareff method for determining soil organic matter, and a proposed modification of the chromic acid titration method. Soil science 37(1), 29–38.
Wang, S., Xu, L., Hao, M., 2022. Impacts of Long-Term Micronutrient Fertilizer Application on Soil Properties and Micronutrient Availability. International Journal of Environmental Research and Public Health, 19(23), 16358.
Williams, C.H., Steinberg, A., 1959. Soil sulphur fractions as chemical indices of available sulphur in some Australian soils. Australian Journal of Agriculture Research 10, 340–352.
Yusuf, A.A., Abdu, N., Chude, V.O., Yusuf, H.A., Pam, S.G., 2005. Response of maize (*Zea mays* L.) to zinc fertilization in relation to Mehlich 1 extractable zinc in Northern Nigeria. Nigerian Journal of Soil and Environmental Research 6, 32–41.