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Distribution of Cationic Micronutrients in Relation to Different Soil Properties and Fractions of Phosphorus in Coastal Soils of West Bengal

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This study aims to establish the relationships between cationic micronutrients and soil properties in 52 surface soils (0-15 cm) collected from coastal areas of West Bengal, India. The initial status of cationic micronutrients and their relationship with soil properties were also studied. The DTPA-extractable micronutrients namely, zinc (Zn), iron (Fe), manganese (Mn) and copper (Cu) ranged from 0.03-2.65, 5.59-68.4, 10.8-49.9 and 0.69-3.71 mg kg^{-1} with mean values of 0.65, 27.3, 33.7 and 1.71 mg kg^{-1}, respectively. Different soil properties namely, pH, organic carbon (OC), electric conductivity (EC), cation exchange capacity (CEC), Olsen-P and different inorganic phosphorus (P) fractions were determined. Results showed a significant negative correlations between pH and Zn, Fe, Mn and Cu, whereas OC showed positive and significant correlations with Zn, Fe and Cu and non-significant positive correlations with Mn. The EC showed the non-significant negative correlations with Fe and Cu and non-significant positive correlation with Zn and Mn. Olsen-P showed the non-significant positive correlations with Zn, Fe and Cu and non-significant negative correlations with Mn. Results also revealed that CEC and EC enhanced the loosely bound-P explaining 47% of total variability. Loosely bound-P and reductant soluble-P showed the significant negative correlations with all the micronutrients. However, Al-P showed the significant positive correlations with Zn, Fe and Cu.

Key words: Cationic micronutrients, phosphorus fractions, soil properties, coastal soils

Like macronutrient, micronutrient fertilization is also important for crop production. Though these elements are required in very small amounts for growth and development of plants, it plays a major role in plant's metabolic activities. Thus, soil must supply micronutrients for desired growth of plants and synthesis of food. Adaption of high yielding varieties under intensive cropping together with high analysis nitrogen (N), phosphorus (P) and potassium (K) fertilizers resulted in decline in the level of micronutrients in the soils to below normal at which the productivity of crops could not be sustained. Deficiency in plant might be occurred due to its low content in soil or due to the unavailability even though they were present in soil. The availability of nutrients in soil depends on many soil properties. So, before fertilizer application, it is very important to know about the soil properties. Keeping these in view the present investigation was undertaken to evaluate the status and distribution of micronutrient cations and their relationships with soil properties and different fractions of P in rice growing coastal soils of West Bengal.

Materials and Methods

Fifty two (52) soil samples were collected from five rice growing blocks of South 24-Parganas district of West Bengal, India at 0-15 cm soil depth. The samples were air-dried, ground and passed through 2-mm sieve before analysis. The surface soil samples were analyzed for various soil properties such as pH and electrical conductivity (EC) (Jackson 1973), organic carbon (OC) (Walkley and Black 1934), cation exchange capacity (CEC) (Harada and Inoko

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1980), available P (Olsen *et al*. 1954). The cationic micronutrients (Fe, Mn, Cu and Zn) were extracted with 0.005 *M* DTPA solution at pH 7.3 following the method as described by Lindsay and Norvell (1978) and determined with the help of an atomic absorption spectrometer (Perkin Elmer model Aanalyst 100). For determination of P fractions, the sequential extraction procedure originally developed by Chang and Jackson (1957), modified by Petersen and Corey (1966) and further modified by Kuo (1996) was used. The relationships among various soil properties, different fractions of P namely, loosely bound-P, aluminium-P (Al-P), iron-P (Fe-P), reductant soluble-P (Res-P) and calcium-P (Ca-P) and micronutrients (Zn, Fe, Mn and Cu) were established using simple correlation.

Results and Discussion

Soil properties

The overall soil reaction (pH) of South 24-Parganas district ranged from 5.28 to 8.46 with a mean value of 6.83 indicating that the soils are acidic to alkaline in nature. The lowest pH (5.69) was noticed in the soil of Mandirbazar block and this might be attributed to the impact of parent material and leaching down of basic cations in soils by heavy rainfall during monsoon (Mini *et al.* 2007). The EC of the soils varied from 0.0006 to 0.0290 dS m^{-1} with a mean value of 0.0055 dS m^{-1}. The low value of EC in these soils might be due to proper management of soil and by the leaching of salts from surface to sub-surface and also due to the application of acidulating fertilizers in salt affected areas (Vijayakumar *et al.* 2011). The OC content in the soils ranged from 0.38 to 20.1 g kg^{-1} with a mean value of 6.06 g kg^{-1}. The CEC of soils ranged from 8.40 to 53.2 cmol(p^+)kg^{-1} with a mean value of 22.0 cmol(p^+)kg^{-1}. The results also showed that out of all inorganic P fractions, Ca-P was recorded as the dominant P in most soils. Similar reports were made by Khan and Mandal (1973) who found that the Ca-P was found to be the major constituent of the inorganic P in soils. The results of the present investigation corroborates the results reported by Abolfazli *et al.* (2012) who also evaluated different fractions of inorganic P as affected by different treatments and showed that Ca-P fraction was the predominant form of P in calcareous soils.

Cationic micronutrients content

The DTPA-extractable Fe content in the soils of South 24-Parganas district ranged from 5.59 to 68.4 mg kg^{-1} with a mean value of 27.3 mg kg^{-1}. The lowest and highest available Fe were registered in soils of Bhuniyapara in Diamond Harbour block and Belsigha in Falta block, respectively. The DTPA-extractable Mn content in soils ranged from 10.8 to 49.9 mg kg^{-1} with mean value of 33.7 mg kg^{-1}. The highest available Mn was recorded at Debipur and lowest at Banki in Falta block. The DTPA-extractable Zn content in soils ranged from 0.03 to 2.65 mg kg^{-1} with mean value of 0.65 mg kg^{-1}. The highest value of available DTPA-Zn was recorded at Baradrone in Diamond Harbour block and lowest value was recorded at Boldari in Falta block. The DTPA-Cu content of the soils ranged from 0.69 to 3.71 mg kg^{-1} with mean value of 1.71 mg kg^{-1}. The highest value was observed at Jagla-Ballavpur in Falta block and lowest at Bhuniyapara in Diamond Harbour block. Based on the critical limit of Fe, Mn, Cu and Zn in soils as 4.5, 1.0, 0.20 and 0.60 mg kg^{-1} reported by Viets (1962), the status of micronutrients were categorised as low and high. All 52 soil samples were recorded high value with respect to DTPA-extractable Fe, Mn and Cu contents while the amount of DTPA-extractable Zn contents were recorded high (H) and low (L) values as depicted in table 2.

Table 1. Physicochemical properties of 52 soil samples of different blocks of South 24-Parganas, West Bengal

Place	pH (1:2.5 H_2O)	EC (1:5) (dS m^{-1})	Organic C (g kg^{-1})	CEC [cmol(p^+) kg^{-1}]	Olsen-P (mg kg^{-1})
Block: Falta; Soil Taxonomy: Fine; Aeric Haplaquepts					
Paschim Durgapur	6.54	0.0052	7.07	23.4	12.0
Dholtikari	5.69	0.0051	12.4	40.5	24.3
Nityanandapur	7.39	0.0006	3.68	23.4	13.3
Kanthalfuli	6.14	0.0050	14.3	23.5	10.0
Srirampur	7.12	0.0053	9.11	25.9	7.50
Chandpala-Anantarampur	6.53	0.0012	12.6	22.1	7.50
Boldari	5.56	0.0074	18.8	17.2	17.5
Belsingha	5.47	0.0018	8.79	11.8	20.0
Swetkalla	6.41	0.0022	10.3	31.2	20.0

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Ramlakha	6.26	0.0049	20.1	21.2	23.0
Punya	7.76	0.0059	5.16	12.3	17.5
Chandideul	7.55	0.0023	5.16	24.5	6.50
Banki	6.80	0.0027	3.82	22.1	23.0
Rukhia	7.54	0.0046	6.69	24.5	13.0
Harindanga	5.85	0.0052	13.6	13.0	13.0
Hogla	6.00	0.0042	10.9	18.8	30.5
Barhybatpur	6.91	0.0008	5.73	15.6	8.5
Debipur	6.53	0.0290	5.36	27.0	17.5
Jagla-Ballavpur	6.07	0.0034	13.2	22.4	15.0
Fatepur	7.68	0.0035	3.44	19.6	8.5
Range	5.47-7.76	0.0006-0.029	3.68-20.1	11.8-40.5	6.5-30.5
Mean	6.59	0.005	9.50	22.0	15.41
Block: Mandirbazar; Soil Taxonomy: Fine Loamy, Aeric Haplaquents					
Kismatnagar	5.37	0.0029	7.84	15.6	13.0
Muraripur	6.21	0.0011	4.20	18.2	16.5
Dhopahat	5.28	0.0015	8.41	30.6	13.0
Purba-Chandpur	5.93	0.0024	7.27	15.6	12.0
Range	5.28-6.21	0.0011-0.003	4.20-8.41	15.6-30.6	12.0-16.5
Mean	5.69	0.0020	6.93	20.0	13.6
Block: Mathurapur; Soil Taxonomy: Fine Loamy, Aeric Haplaquents					
Kaipukur	7.60	0.0120	5.73	16.45	14.0
Block: Kulpi; Soil Taxonomy: Fine; Aeric Haplaquepts					
Bishnurampur	7.30	0.0031	3.05	15.6	13.0
Ramkishorepur	6.15	0.0033	5.93	33.6	6.50
Barandali	6.45	0.0020	8.37	20.8	10.0
Hanra	7.85	0.0093	5.33	14.1	5.50
Ramrampur	6.63	0.0096	3.24	36.4	8.50
Harinarayanpur	6.10	0.0026	8.37	16.5	8.50
Jamberia	7.40	0.0027	4.56	16.5	10.0
Barberia	7.41	0.0058	5.51	28.9	66.5
Manika	7.26	0.0010	6.85	20.8	7.50
Gayenpara	7.43	0.0033	3.42	13.0	8.50
Mukundapur	6.33	0.0024	3.81	28.6	7.50
Deora	7.82	0.0016	3.04	47.6	8.50
Deria	6.75	0.0015	6.47	39.2	10.0
Range	6.10-7.85	0.0010-0.0096	3.04-8.37	13.0-47.6	5.5-66.5
Mean	6.99	0.0037	5.23	25.5	13.1
Block: Diamond Harbour; Soil Taxonomy: Fine; Aeric Haplaquepts					
Baradrone	8.23	0.0102	2.47	11.2	8.50
Banbahadurpur	7.66	0.0055	0.38	36.4	6.50
Bolsiddi	7.36	0.0025	1.14	28.0	13.0
Atkrishnarampur	7.59	0.0043	4.76	28.0	8.50
Narayanpur	8.24	0.0049	1.72	8.40	12.0
Gouripur	8.05	0.0051	3.42	28.0	10.0
Bhuniyapara	7.91	0.0054	2.47	16.8	8.50
Kanpur	8.26	0.0050	3.04	28.0	8.50
Sultanpur	8.46	0.0057	3.04	18.2	10.0
Dhanberia	7.73	0.0016	4.56	26.0	8.50
Hansdahara	7.13	0.0016	5.13	28.0	13.0
Hatugunge	7.52	0.0147	0.95	15.6	8.50
Baria	7.87	0.0020	3.99	53.2	8.50
Lalbati	8.04	0.0010	3.99	36.4	10.0
Range	7.13-8.46	0.0010-0.015	0.38-5.13	8.40 - 53.2	6.50-13.0
Mean	7.29	0.0050	2.93	25.9	9.57
Grand mean:	6.83	0.0055	6.06	22.0	13.1
Range:	5.28-8.46	0.0006-0.029	0.38-20.1	8.40-53.2	5.5-66.5

Table 2. Distribution of cationic micronutrients and different phosphorus fractions samples of different blocks of South 24-Parganas, West Bengal

Place	Phosphorus fractions (mg kg^{-1})					Micronutrients (mg kg^{-1})			
	Loosely bound-P	Al-P	Fe-P	Res-P	Ca-P	Zn	Fe	Mn	Cu
Block: Falta, Soil Taxonomy: Fine; Aeric Haplaquepts									
Paschim Durgapur	113	125	625	25	650	1.50 (H)	31.6	32.9	1.63
Dholtikari	113	125	700	25	375	1.74 (H)	47.6	30.3	1.13
Nityanandapur	100	25	625	25	375	1.45 (H)	9.18	31.7	1.04
Kanthalfuli	113	200	700	25	550	1.46 (H)	57.0	42.1	3.07
Srirampur	113	150	575	25	250	2.11 (H)	24.6	38.5	2.02
Chandpala-Anantarampur	125	75	675	25	1000	1.65 (H)	45.2	33.4	2.07
Boldari	125	150	575	25	1075	0.03 (L)	62.8	41.0	2.31
Belsingha	125	225	725	25	900	1.45 (H)	68.4	28.2	2.41
Swetkalla	113	100	725	25	450	1.77 (H)	39.2	43.9	1.78
Ramlakha	125	125	400	25	500	1.16 (H)	62.4	16.4	2.93
Punya	175	300	300	25	675	0.38 (L)	17.7	32.8	1.96
Chandideul	138	175	725	25	525	0.23 (L)	7.47	32.9	0.85
Banki	125	150	575	25	600	0.54 (L)	39.7	10.8	2.27
Rukhia	138	125	800	25	400	0.43 (L)	12.4	31.0	1.65
Harindanga	138	75	500	25	600	0.61 (M)	59.6	49.6	2.77
Hogla	138	175	675	25	1025	0.80 (M)	61.2	43.9	2.82
Barhybatpur	88	100	725	25	625	0.16 (L)	23.6	37.1	1.90
Debipur	113	100	175	50	825	1.36 (H)	25.3	49.9	2.15
Jagla-Ballavpur	163	100	350	25	575	0.87 (M)	46.6	31.3	3.71
Fatepur	163	125	350	25	650	0.30 (L)	8.00	34.0	1.08
Range	88-163	25-300	175-800	25-50	250-1075	0.03-2.11	7.47-68.4	10.8-49.9	0.85-3.71
Mean	127	136	575	26.3	631.3	1.00	37.5	34.6	2.08
Block: Mandirbazar, Soil Taxonomy: Fine Loamy, Aeric Haplaquents									
Kismatnagar	163	100	450	25	400	0.70 (M)	58.2	49.3	2.60
Muraripur	163	100	675	25	275	0.50 (L)	45.2	43.1	1.70
Dhopahat	163	100	650	25	850	0.90 (M)	62.0	42.0	3.02
Purba-Chandpur	163	125	725	50	975	0.28 (L)	51.1	38.5	2.19
Range	163	100-125	450-725	25-50	275-975	0.28-0.90	45.2-62.0	38.5-49.3	1.70-3.02
Mean	163	106	625	31	625	0.59	54.1	43.2	2.38
Block: Mathurapur, Soil Taxonomy: Fine Loamy, Aeric Haplaquents									
Kaipukur	163	125	600	25	1050	0.36	18.0	29.0	1.90
Block: Kulpi, Soil Taxonomy: Fine; Aeric Haplaquepts									
Bishnurampur	163	125	700	25	950	0.28 (L)	17.6	33.9	1.19
Ramkishorepur	163	125	725	25	1025	0.28 (L)	19.9	33.3	1.72
Barandali	363	38	325	88	625	0.70 (M)	45.2	37.8	2.62
Hanra	375	38	475	88	500	0.28 (L)	12.0	31.6	1.37
Ramrampur	375	38	663	88	625	0.26 (L)	13.3	30.4	1.05
Harinarayanpur	413	38	638	100	750	0.35 (L)	5.96	33.8	1.83
Jamberia	413	63	425	88	875	0.22 (L)	9.78	30.7	1.29
Barberia	400	125	613	88	875	0.56 (L)	34.4	27.9	1.69
Manika	375	38	563	75	1000	0.19 (L)	21.1	31.9	1.41
Gayenpara	388	38	525	88	875	0.21 (L)	64.2	29.2	0.75
Mukundapur	388	50	663	100	375	0.50 (L)	14.3	34.2	1.16
Deora	450	38	588	100	250	0.23 (L)	8.64	30.8	1.00
Deria	425	50	638	88	625	0.36 (L)	15.3	28.2	2.21
Range	163-450	38-125	375-725	25-100	250-1025	0.19-0.70	5.96-64.2	27.9-37.8	0.75-2.62
Mean	361	62	580	80	719	0.34	21.7	31.8	1.48
Block:Diamond Harbour, Soil Taxonomy: Fine; Aeric Haplaquepts									
Baradrone	438	38	375	88	500	2.65 (H)	7.76	34.2	0.92
Banbahadurpur	450	50	250	88	875	0.35 (L)	11.2	34.2	1.48
Bolsiddi	425	38	125	125	500	0.25 (L)	7.93	31.7	1.37

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Atkrishnarampur	450	38	125	100	375	0.14 (L)	9.65	30.9	1.31
Narayanpur	425	50	375	88	875	0.45 (L)	11.8	30.9	0.75
Gouripur	450	50	375	125	625	0.27 (L)	7.38	30.5	1.62
Bhuniyapara	450	50	500	100	875	0.19 (L)	5.59	31.4	0.69
Kanpur	450	63	87.5	163	125	0.20 (L)	7.35	31.6	0.99
Sultanpur	450	50	87.5	138	750	0.12 (L)	7.52	28.3	1.09
Dhanberia	475	63	625	125	375	0.69 (M)	18.0	33.2	1.20
Hansdahara	438	63	375	125	625	0.46 (L)	28.1	34.0	1.78
Hatugunge	450	63	1000	150	750	0.32 (L)	10.7	28.9	0.73
Baria	513	50	625	113	625	0.23 (L)	10.9	30.8	1.45
Lalbati	488	63	250	125	750	0.33 (L)	12.2	31.8	1.26
Range	425-513	38-63	88-1000	88-163	125-875	0.12-2.65	5.59-28.1	28.3-34.2	0.69-1.78
Mean	454	52	370	118	616	0.47	11.2	31.6	1.19
Grand mean	253	96	550	56	728	0.65	27.3	33.7	1.71
Range	88-513	25-300	88-1000	25-163	125-1050	0.03-2.65	5.59-68.4	10.8-49.9	0.69-3.71

Zn: <0.60 Low, 0.60-1.0 Medium, >1.0 High; Fe: <4.5 Low, >4.5 High; Mn: <1.0 Low, >1.0 High; Cu: <0.2 Low, >0.2 High; Concentration expressed in mg kg^{-1}

Relationships among micronutrients, soil properties and different P fractions in soil

Simple correlation studies between extractable micronutrients such as Zn, Cu, Mn and Fe were made with soil properties and different fractions of P are shown in table 3. Available Zn in the experimental soil was found negatively and significantly correlated with pH of the soil (r = -0.293*). The results are in agreement with the work done by Vadivelu and Bandyopadhyay (1995) and Tundup and Akbar (2014). The solubility of native forms of Zn is highly pH dependent and decreased by a factor of 100 per cent per unit raise in pH (Lindsay 1972). The correlation coefficient (r) obtained between Zn and OC was 0.388**, indicating that Zn is positively and significantly correlated with organic matter. The positive correlation may be due to the formation of metal organic complexes between organic matter and Zn that protect it from leaching. These results are similar to the findings of Chinchmalatpure *et al.* (2000) and Yadav and Meena (2009). Available Zn showed non-significant positive correlation with EC, Olsen-P, Fe-P and significant positive correlation with Al-P (r = 0.298*). Results also showed significantly negative correlation with loosely bound-P (r = -0.556***) and Res-P (r = -0.485***) and non-significantly negative correlation with Ca-P.

Table 3. Correlation coefficients (r) between available micronutrients with soil properties and different P fractions

Soil properties	Correlation coefficients (r)			
	Zn	Fe	Mn	Cu
pH	-0.293*	-0.636***	-0.360**	-0.505***
EC	0.177	-0.131	0.232	-0.033
OC	0.388**	0.631***	0.176	0.536***
Olsen-P	0.102	0.202	-0.062	0.154
Loosely bound P	-0.556***	-0.462***	-0.307*	-0.436**
Al-P	0.298*	0.373**	0.088	0.369**
Fe-P	0.154	0.086	0.022	-0.099
Res-P	-0.485***	-0.386**	-0.273*	-0.395**
Ca-P	-0.056	-0.056	0.084	0.055

* = 5%; ** = 1% and *** = 0.1% level of significance

The DTPA-Fe (Table 3) bears negative and significant relationship with pH (r = -0.636***). The reduction in availability of Fe with increasing pH might be attributed to conversion of Fe^{2+} to Fe^{3+} ions. Significant effect of pH on Fe availability has been reported by Patil *et al.* (2003) and Sharma *et al*. (2003). Similar observation was also reported by Rajkumar *et al*. (1996), Chatterji *et al*. (1999) and Chinchmalatpure *et al.* (2000). Positive significant correlation between OC and DTPA-extractable Fe was found (r = 0.631***) which indicates that the soil rich in organic matter contain more Fe. These results are in agreement with Khalifa *et al*. (1996). Results on available Fe showed significantly negative correlation with loosely bound-P (r = -0.462***) and Res-P (r = -0.386**). This may be due to the fixation of P in the form of Fe-phosphate which decreases the P availability. It shows the non-significant positive correlation with Olsen-P, Al-P, Fe-P and significantly positive correlation with available Zn. Non-significantly negative correlation was found between EC and Ca-P.

Available Mn (Table 3) showed significantly negative correlation with pH (r = -0.360**). This is because Mn may get complexed by organic matter, formation of manganese oxides, and precipitation of Mn by calcium carbonate. Dissociation of these complexes depends on pH, wherein by lowering the pH, the availability of Mn increases (Smiley *et al.* 1986). These results are in agreement with Chattopadhyay *et al.* (1996). Positive and non-significant correlation was found between Mn and OC (r = 0.176). Similar result were obtained by Khattak *et al*. (1994) and Chinchmalatpure *et al*. (2000). Non-significant positive correlation was found between Mn and EC, Mn and Al-P, Mn and Fe-P, Mn and Ca-P, Mn and Zn and significant positive correlation between Mn and Fe. Significant negative correlation was found with loosely bound-P (r = -0.307*), Res-P (r = -0.273*) and non-significant negative correlation was with Olsen-P. This means with increasing the availability of Mn, loosely bound-P and reductant soluble-P decreases.

Copper (Table 3) was found negatively and significantly correlated with soil pH (r = -0.505***). It indicates that a decline in pH of the soil leads to significant increase in Cu availability. These results are in line with that reported by Jalali and Takkar (1989) in some benchmark soils of Kashmir. Similar correlation coefficients were also worked out by Bhandari and Randhawa (1985). Data indicated that Cu was positively and significantly correlated with soil OC (r = 0.536***). Presumably, organic matter supplies complexing agents that promote the availability of certain elements (Hodgson 1963). Similar results were reported earlier by others (Sangwan and Singh 1993; Khalifa *et al*. 1996; Rajakumar *et al*. 1996; Tundup and Akbar 2014). Results showed positive significant correlations of available Cu with Al-P (r = 0.369**), DTPA-Fe (r = 0.708***) and DTPA-Mn (r = 0.285*) and positive non-significant correlations with Olsen-P, Ca-P and DTPA-Zn. Again available Cu showed negative significant correlation with loosely bound-P (r = -0.436**), Res-P (r = -0.395*), whereas negative correlation with EC and Fe-P.

Regression equations as affected by micronutrients, soil properties and different P fractions in soil

The results showed that only Fe was found significant predictor to explain Olsen-P at 5% level of significance. However, along with Fe, if EC, CEC, Cu and Zn increased, Olsen-P also increased. Again Mn and OC if increased (or decreased), Olsen-P decreased (or increased). This equation could be explained by 24% of total variability of Olsen-P. Further, it was observed from the Eq. (i) that in spite of same coefficient value 0.24 for Zn and Fe, Zn did not show a significant predictor with respect to Olsen-P which might be due to the antagonistic effects between Zn and P in soil (Das 2018).

Olsen-P = 15.43 + 364.17 EC – 0.27 OC + 0.09 CEC + 0.24 Zn + 0.24 Fe* – 0.37 Mn + 1.01 Cu …Eq. (i)

Where, R^2 = 0.24, Adj R^2 = 0.012 and SE (est.) = 8.64.

From the Eq. (ii), it is observed that Fe was only positively significant predictor to explain Fe-P at 1% level of significance. This equation could be explained by 13% of total variability of Olsen P.

Olsen P = 8.59 + 0.17 Fe** …Eq. (ii)

Where, R^2 = 0.13, Adj R^2 = 0.12, SE (est.) = 8.64

The results revealed that CEC and EC enhanced the loosely bound P, whereas OC, Zn, Cu, Fe and Mn reduced the same but no effect was found significant (Eq. iii). This equation could be explained by 47% of total variability of loosely bound P.

Loosely bound P = 458.76 + 528.01 EC – 8.89 OC + 2.75 CEC - 58.07 Zn – 1.05 Fe – 2.10 Mn – 32.24 Cu …Eq. (iii)

Where, R^2 = 0.47, Adj R^2 = 0.39, SE (est.) = 117.84

From the R^2 value of the equation (Eq. iv), it was revealed that OC and Zn were negatively significant predictor to explain loosely bound-P at 1% and 5% level of significance respectively. This equation could be explained by 39% of total variability of loosely bound-P.

Loosely bound P = 428.87 – 17.50 OC** – 61.85 Zn* …Eq. (iv)

Where, R^2 = 0.39, Adj R^2 = 0.36, SE (est.) = 120.36

The results showed that EC, OC, Zn, Fe and Cu enhanced Al-P, whereas Mn and CEC decreased the Al-P content but no effect was found significant (Eq. v). This equation could be explained by 27% of total variability of Al-P.

Al-P = 84.79 + 1365.08 EC + 0.92 OC – 0.98 CEC + 3.99 Zn + 0.52 Fe – 0.99 Mn + 21.10 Cu …Eq. (v)

Where, R^2 = 0.27, Adj R^2 = 0.16, SE (est.) = 51.75

From the R^2 value of the equation (Eq. vi), it was found that Cu was only significant predictor to explain Al-P at 1% level of significance. This equation could be explained by 19% of total variability of Al-P.

Al-P = 33.45 + 34.43 Cu** …Eq. (vi)

Where, R^2 = 0.19, Adj R^2 = 0.17, SE (est.) = 51.36

Results revealed that Fe, OC, Zn, CEC and Mn, enhanced Fe-P content, whereas EC and Cu reduced the same but no effect was found significant (Eq. vii). This equation could be explained by 17% of total variability of Fe-P.

Fe-P = 480.91- 8718.31 EC + 8.80 OC + 1.32 CEC + 38.36 Zn + 2.88 Fe + 1.57 Mn – 96.22 Cu …Eq. (vii)

Where, R^2 = 0.17, Adj R^2 = 0.04, SE (est.) = 198.87

The results revealed that only Fe was found positively significant predictor to explain Fe-P at 5% level of significance (Eq. viii). This equation could be explained by 14% of total variability of Fe-P.

Fe-P = 562.85 – 7187.12 EC + 3.91 Fe* – 67.63 Cu …Eq. (viii)

Where, R^2 = 0.14, Adj R^2 = 0.08, SE (est.) = 194.35

The results found that with an increase in OC, Fe, Mn, Cu and Zn in soil, the reductant soluble P (Res-P) decreased and vice-versa (Eq. ix). Again, if CEC and EC increased (or decreased), reductant soluble P content increased (or decreased).This equation could be explained by 45% of total variability of reductant soluble P.

Res-P = 114.48 + 945.44 EC – 2.33 OC + 0.72 CEC – 17.15 Zn – 0.23 Fe – 0.59 Mn – 10.71 Cu …Eq. (ix)

Where, R^2 = 0.45, Adj R^2 = 0.36, SE (est.) = 34.38

From the R^2 value of the equation (Eq. x), it was found that only OC was observed negatively significant predictor to explain Res-P at 1% level of significance. This equation could be explained by 31% of total variability of reductant soluble P.

Res-P = 100.76 – 5.64 OC** …Eq. (x)

Where, R^2 = 0.31, Adj R^2 = 0.30, SE (est.) = 35.94

The results found that the Zn content was only negatively significant predictor to explain Ca-P at 5% level of significance (Eq. xi). Along with Zn, if CEC, OC and Mn increased (or decreased), Ca-P decreased (or increased). Further, with an increase in Fe, EC and Cu content in soil, the Ca-P content was increased and vice-versa. This equation could be explained by 21% of total variability of Ca-P.

Ca-P = 850.88 + 6651.74 EC – 3.07 OC – 6.08 CEC – 137.30 Zn* + 3.45 Fe – 2.78 Mn + 18.02 Cu …Eq. (xi)

Where, R^2 = 0.21, Adj R^2 = 0.09, SE (est.) = 229.57

From the R^2 value of the equation (Eq. xii), it was found that CEC was found negatively significant predictor to explain Ca-P at 5% level of significance. This equation could be explained by 8% of total variability of Ca-P.

Ca-P = 831.42 – 7.39 CEC* …Eq. (xii)

Where, R^2 = 0.08, Adj R^2 = 0.07, SE (est.) = 232.45

Principal Component Analysis

Principal component analysis (PCA) of different soil properties, DTPA extractable micronutrients and different fractions of P in soil samples are displayed depending upon regression factors and weighed coefficients as included in table 4. Total 5 components were extracted explaining 74.8% of variability of such distribution study. Here, first PCA could be explained by 37.8% of total variance. In this PCA, with an increase in Fe, OC, Cu, Al-P, Zn, Fe-P, Mn, Olsen-P and Ca-P content in soil, loosely bound-P, reductant soluble-P, pH, CEC and EC decreased and vice versa. Second PC further could be explained by 10.3% of

Table 4. Principal component analysis of different soil properties, DTPA extractable micronutrients and different fractions of P in 52 soil samples of South 24-Parganas district of West Bengal

Variables	Component matrix				
	1	2	3	4	5
pH	-0.834	-0.001	0.252	-0.288	0.012
Electrical conductivity (EC)	-0.015	0.572	0.645	-0.103	0.093
Organic C (OC)	0.799	0.097	-0.131	0.209	0.182
Cation exchange capacity (CEC)	-0.250	0.248	-0.571	-0.056	0.417
Olsen-P	0.363	-0.112	0.247	-0.187	0.723
Loosely bound-P	-0.866	-0.022	-0.035	0.301	0.220
Aluminium P (Al-P)	0.670	-0.141	0.286	-0.389	0.068
Iron P (Fe-P)	0.399	-0.402	-0.351	-0.351	-0.228
Reductant soluble P (Res-P)	-0.851	0.074	0.004	0.289	0.218
Calcium P (Ca-P)	0.187	-0.570	0.512	0.295	-0.019
DTPA-Zn	0.453	0.547	-0.072	-0.366	-0.002
DTPA-Fe	0.839	-0.051	-0.048	0.288	0.160
DTPA-Mn	0.364	0.461	0.097	0.374	-0.447
DTPA-Cu	0.778	0.085	-0.058	0.368	0.208
Eigen value	5.295	1.445	1.372	1.204	1.161
% of Variance	37.819	10.32	9.799	8.597	8.292
Cumulative %	37.819	48.139	57.938	66.535	74.827

variance, where specific conductance, Zn, Mn, CEC, OC, Cu, Res-P have been found to be increased with the simultaneous decrease in Ca-P, Fe-P, Al-P, Olsen-P, Fe, loosely bound P, pH in soils. Third PC could be explained by 9.80% of total variance where EC, Ca-P, Al-P, pH, Olsen-P, Mn, reductant soluble P increased, the CEC, Fe-P, OC, Zn, Cu, Fe, loosely bound-P was decreased. Fourth PC could be explained by 8.60% of total variance where Mn, Cu, loosely bound P, Ca-P, Res-P, Fe, OC contents was recorded an increase whereas Al-P, Zn, Fe-P, pH, Olsen P, EC, CEC of soils were found to be decreased. Fifth PC could be explained by 8.29% of total variance in which Olsen-P, CEC, loosely bound-P, Res-P, Cu, OC, Fe, EC, Al-P, pH were increased and decreased the contents of Mn, Fe-P, Ca-P and Zn in soils.

Conclusions

From the study conducted in the soils of coastal areas of West Bengal, it may be concluded that the soil properties such as pH, electrical conductivity, organic carbon and Olsen-P have significant influence on cationic micronutrients in soil. The results also indicated that out of all the inorganic P fractions, calcium phosphate constitutes the dominant fraction in most of the soils of coastal areas of West Bengal.

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