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Vertical distribution and dynamics of iron, manganese and aluminium in rice soils of Kuttanad, Kerala

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Abstract : The vertical distribution of Fe, Mn and Al in rice soils of Kuttanad and their dynamics in relation to the operation of the regulator/barrage constructed for salinity protection was studied. Fifteen soil profiles and 97 surface soil samples were collected from the 10,200 ha of rice soils of Kuttanad during monsoon and post-monsoon seasons, which coincides with the opening and closure of regulator, respectively. About 72 per cent of the tract belongs to Typic Sulfaquents subgroup and seven per cent each to Typic Psammaquents, Aquic Udifluvents, Mollic Fluvaquents and Fluvaquentic Dystrudepts. The total Fe and Al contents ranged from 2.75 to 7.72 and 1.61 to 8.28 per cent, respectively with the lowest values for Typic Psammaquents. The dithionite citrate extractable (DCE) Fe and Al also followed the same trend as that of total content of nutrients. The percentage of DCE to total Fe ranged from 62.2 to 90.2 and that of Al from 60.2 to 95.2, indicating majority of Fe and Al exists in free form. The total Mn content of the tract is also very high ranging from 36 to 308 mg kg^{-1}. Fe and Al behaved in similar way showing an increase towards post-monsoon season i.e. after the closure of regulator whereas Mn indicated a reverse trend.

Additional key words **:** *Salinity, behaviour of nutrients, rice*

Introduction

Kuttanad, the rice bowl of Kerala is a deltaic formation lying 0.6 to 2.2 m below MSL. It is located in and around the Vembanad lake on the western coast of India, comprising an area of 1100 sq. km. presently experiences severe decline in rice production (KAU 1998). Major reasons attributed are the deterioration of soil health as evidenced by the increase in acidity and concentration of Fe, Al and Mn to toxic levels and pest and disease menace. Fe and Al toxicity is very wide spread in acid sulphate areas of Kuttanad often leading to a decline of yield of 50 to 70 per cent (Thampatti *et al.* 2005). Hydrology plays a major role in rice cultivation here, since the tract is subjected to periodical flooding during monsoons and intrusion of salinity during summer. Without preventing the saline water intrusion due to tidal inflow from the Arabian Sea, the cultivation of *punja* (summer) rice is not possible in Kuttanad. To prevent this, a regulator was constructed during 1975, at the narrowest portion of the Vembanad lake which is contiguous with Arabian Sea and the shutters of the regulator will be kept closed during April to December. The prevention of saline water entry has considerably altered the soil environment by converting this brackish-water tract to a fresh-water tract during major part of the year. This has also led to the lowering of water table on the southern side of the regulator during summer season. There was a regular increase in soil acidity after the construction of regulator. Even continuous submergence fails to increase the soil pH beyond 4.5 in most of the areas of Kuttanad and has influenced the dynamics and distribution of nutrients especially the micronutrient cations. The area experienced asteep decline in electrical conductivity and organic matter content (Kuruvila and Patnaik 1994; Thampatti and Jose 2000, and 2005). Frequent fluctuations in water table resulted in upward and downward movement of elements in accordance with the movement of waterfront, aggravating the loss of soluble constituents. Continuous submergence has maintained Fe and Mn in soluble form due to soil reduction. The extractable and water soluble Al content of these soils also increased due to the persistence of a pH below 4.5 (Raju 1988; KAU 1994). The soils of Kuttanad are generally rich in

Fe, Mn and Al and the above conditions often results in their toxicity in these soils. Draining out of these water containing toxic quantities of Fe, Mn and Al to the surrounding canals often leads to the death of aquatic organisms (Nair and Pillai 1990). Hence the present paper attempts an evaluation on the vertical distribution of different forms of Fe, Mn and Al, which are present in toxic quantities in this tract and their dynamics in relation to the operation of regulator and weather conditions. Information on the vertical distribution pattern and dynamics of these toxic elements will be very helpful in developing proper remedial measures against these maladies.

Materials and Methods

Out of the 50,000 ha of rice fields on the upstream side of the regulator, North Kuttanad comprising 10,200 ha of rice was selected for the study. The region has a humid tropical climate with mean annual rainfall of 3000 mm, out of which 80 % occurs during June to September resulting in floods. After the cession of monsoons the saline water from the Arabian Sea enters in to Vembanad lake and from there the water spreads to entire Kuttand, making the soils predominantly acid saline. The moisture regime of the tract is aquic and the temperature regime is iso-hyperthermic.

Fifteen pedons were studied at an interval of 5 km and classified (Soil Survey Staff 1992). From the 27 randomly selected polders of the area, 97 surface soil samples (0-15 cm depth) were collected before and after the closure of Thanneermukkom regulator which coincides with the monsoon and summer seasons (post monsoon), respectively. Standard procedures were followed for the determination of particle size (Black 1965), pH, organic carbon, total and water soluble Fe, Mn and Al (Page 1982), available Fe and Mn (Lindsay and Norwell 1978). Free form of Fe, Mn and Al were determined in the sodium citrate (17%) – sodium dithionate (1.7%) extract as described by Holmgren (1967) and exchangeable Al by the method described by Yuan (1959).

Results and Discussion

The relevant soil properties and vertical distribution of different forms of Fe are presented in tables 1 and 2 respectively. These soils are rich in Fe and hence the reduction of Fe is more dominant than Mn. The concentration of iron usually exceeds the total amount of other redox elements by a factor of 10 or more. Five to fifty per cent of free iron oxides present in soil may be reduced within a few weeks of flooding (Kabeerathumma and Patnaik 1978; Raju 1988). The total Fe ranged from 2.75 to 7.72 per cent. The variation in total Fe with depth was not uniform. The lithological discontinuity in the profile may be the major reason for this non-uniformity. The lowest value was noted for Typic Psammaquents. The DCE (Dithionate Citrate Extractable) Fe also followed the same trend. The percentage of DCE to total Fe ranged from 62.2 to 90.2 indicating most of the Fe existed in free form. The DTPA-extractable Fe was also the lowest in Typic Psammaquents. But the water soluble Fe behaved in a different way. Shortage of binding agents like clay and organic matter in these soils might have resulted in a major part of Fe in water soluble form.

The total Mn content of Kuttanad soils generally ranged from 28 to 350 mg kg^{-1} (Rajendran and Aiyer 1981; KAU 1994). The total Mn content (Table 2) of the study area is also very high ranging from 36 to 308 mg kg^{-1}. Among the different subgroups, Typic Psammaquents recorded comparatively higher values which is quite contrary to the trend of Fe. The highest value was recorded in C4 layer of Typic Sulfaquents and the lowest value in Mollic Fluvaquents. The variation in total Mn content showed by different subgroups was very wide.

The DCE Mn did not show much variation among different soil subgroups. The percentage contribution of DCE to total Mn varied from 26.9 to 86.5 showing very wide variation in the extent of free Mn. Sandy textured soils showed comparatively lower amount of Mn in DCE. The area is not deficient in available Mn and subgroups Typic Sulfaquents and Typic Psammaquents showed very high values for it. The water soluble Mn content varied from 1 to 5 mg kg^{-1}. The study area contains toxic quantities of Fe and Mn.

Aluminium is the major exchangeable cation in these soils and Al toxicity is common in many parts of Kuttanad (Kuruvila and Patnaik 1994). The total Al content (Table 3) of soils varied from 1.61 to 8.28 per cent. All the soil subgroups except Typic

Table 1. General soil properties (representative profile)

Soil subgroup	Horizon	Depth cm	Colour Moist	Sand	Silt	Clay	Texture	Organic carbon	pH	Base saturation
					(%)			(g kg^{-1})		(%)
Typic Sulfaquents	Ap	0-15	10YR 3/2	64.7	9.0	24.8	scl	30.0	4.5	22.9
	C1	15-25	10YR 7/1	93.1	5.1	1.0	s	13.0	3.3	23.6
	C2	25-37	10YR 5/1	79.3	5.6	13.3	ls	28.0	2.0	34.6
	C3	37-77	10YR 2.5/1	20.5	17.3	60.6	c	162.1	2.6	32.2
	C4	77-110+	10YR 3/1	22.9	17.2	59.9	c	36.0	3.3	35.6
Typic Psammaquents	Ap	0-15	10YR 3/2	81.6	10.1	6.3	ls	6.4	4.6	34.6
	C1	15-35	10YR 3/2	84.9	3.0	10.2	ls	2.8	6.1	40.2
	C2	35-120+	10YR 3/2	84.9	3.0	10.2	ls	10.3	5.5	42.1
Aquic Udifluvents	Ap	0-15	10YR 4/2	74.8	2.4	21.1	scl	52.3	5.0	26.8
	C1	15-36	10YR 4/1	73.5	15.4	9.7	sc	96.8	3.4	10.2
	C2	36-120+	10YR 3/1	73.5	15.4	9.7	sc	68.0	4.8	24.5
Mollic Fluvaquents	Ap	0-15	10YR 4/2	54.2	37.2	8.0	scl	13.2	4.0	40.7
	C1	15-35	10YR 3/1	57.7	21.0	19.8	scl	7.7	4.2	26.0
	C2	35-78+	10YR 4/1	58.7	19.0	20.0	scl	14.9	4.2	28.0
Fluvaquentic Dystrudepts	Ap	0-20	10YR 4/4	54.0	20.1	25.6	scl	21.2	5.3	33.7
	Bw1	20-64	10YR 5/3	49.2	25.9	24.1	scl	20.7	4.5	41.0
	Bw2	64-95+	10YR 5/2	56.6	16.2	26.5	sicl	27.5	4.2	38.0

Table 2. Distribution of different forms of Fe and Mn in soils (representative profile)

Soil Subgroup	Hori zon	Different forms of Fe					Different forms of Mn				
		Total	DEC	%of DCE to Total	DTPA extra-ctable	WS	Total	DEC	% of DCE to Total	DTPA extra-ctable	WS
		%			mg kg^{-1}		mg kg^{-1}			mg kg^{-1}	
Typic Sulfaquents	Ap	4.43	3.23	72.9	329	23	88	54.3	48	10	3
	C1	3.52	2.82	80.1	334	25	76	51.3	39	16	2
	C2	3.29	2.17	66.0	462	32	36	66.7	24	13	3
	C3	4.72	3.38	71.6	487	37	130	43.1	56	25	3
	C4	7.51	5.76	76.7	488	40	308	26.9	83	15	5
Typic Psammaquents	Ap	5.45	4.16	76.3	260	23	218	26.6	58	13	3
	C1	2.75	1.71	62.2	218	25	98	44.8	44	14	3
	C2	3.49	2.23	63.9	276	34	100	46.0	46	10	2
Aquic Udifluvents	Ap	5.75	5.19	90.2	335	28	84	58.3	49	4	2
	C1	7.72	5.21	67.5	235	25	26	55.5	20	3	1
	C2	3.01	2.14	71.0	319	30	90	51.1	46	4	2
Mollic Fluvaquents	Ap	4.62	3.73	80.7	281	19	52	86.5	45	7	3
	C1	4.59	3.21	69.9	240	18	70	55.7	39	6	2
	C2	4.87	3.49	71.7	228	24	94	55.3	52	7	3
Fluvaquentic Dystrudepts	Ap	7.1	6.22	87.6	321	18	64	39.1	25	2	1
	Bw1	5.19	4.01	77.2	329	20	94	57.4	54	8	4
	Bw2	5.33	4.31	80.9	359	24	156	58.3	91	10	2

DCE = Dithionite citrate extractable; WS = Water soluble

Table 3. Distribution of different forms of Al in soils (representative profile)

Soil subgroup	Horizon	Different forms of Al				
		Total	DCE	% of DCE to Total	KCL extractable	WS
		%			cmol kg^{-1}	mg kg^{-1}
Typic Sulfaquents	Ap	8.28	6.24	75.4	1.77	3
	C1	4.88	3.37	69.1	2.50	4
	C2	1.91	1.82	95.2	1.50	4
	C3	3.48	2.52	72.1	2.19	4
	C4	3.87	2.66	68.7	1.22	4
Typic Psammaquents	Ap	2.07	1.31	63.2	0.57	3
	C1	1.97	1.24	62.9	0.38	4
	C2	2.52	1.65	65.5	0.67	5
Aquic Udifluvents	Ap	2.44	1.89	77.5	1.33	5
	C1	1.61	0.97	60.2	0.64	6
	C2	5.27	3.94	74.7	1.06	6
Mollic Fluvaquents	Ap	4.76	2.40	50.4	1.38	5
	C1	5.31	3.88	73.1	1.31	7
	C2	4.23	3.06	72.3	1.01	8
Fluvaquentic Dystrudepts	Ap	6.52	4.38	67.2	0.59	2
	Bw1	5.08	3.91	76.9	0.62	5
	Bw2	4.96	3.91	78.8	1.01	5

DCE = Dithionite citrate extractable; WS = Water soluble

Table 4. Dynamics of Fe, Mn and Al in relation to climatic conditions

Soil subgroup	Season	Fe			Mn			Al	
		Av. mg kg^{-1}	Ex. cmol kg^{-1}	WS mg kg^{-1}	Av. mg kg^{-1}	Ex. cmol kg^{-1}	WS mg kg^{-1}	Extractable cmol kg^{-1}	WS mg kg^{-1}
Typic Sulfaquents	Monsoon	389	0.17	15	12	0.018	4	1.57	4
	Post- monsoon	529	0.22	43	10	0.014	3	4.47	6
Typic Psammaquents	Monsoon	249	0.12	20	18	0.009	2	2.87	2
	Post- monsoon	565	0.19	27	6	0.008	1	2.98	3
Aquic Udifluvents	Monsoon	442	0.21	16	9	0.04	10	4.59	4
	Post- monsoon	798	0.37	18	4	0.04	1	4.69	10
Mollic Fluvaquents	Monsoon	484	020	15	18	0.05	13	1.52	1
	Post- monsoon	498	0.23	18	13	0.04	10	2.50	3
Fluvaquentic Dystrudepts	Monsoon	231	0.18	13	10	0.009	8	2.27	2
	Post- monsoon	313	0.22	16	8	0.008	5	2.83	4

Av = Available; Ex = Exchangeable; WS = Water soluble

Psammaquents were high in total Al content. The DCE Al content was also very high and it ranged from 60.2 to 95.2 per cent of total Al, indicating that more than half of Al exists in free form. The extractable Al was also the lowest for Typic Psammaquents sub group. The water soluble Al was also high and its content vary from 2 to 8mg kg^{-1}. The very low soil pH enabled Al to remain in water soluble form in quantities sufficient to interfere with crop growth.

It was noted that Fe and Al behaved in similar way showing an increase towards post monsoon season i.e. after the closure of regulator. The increase in concentration of Fe and Al after the closure will adversely affect the growth of rice by creating their toxicity. The problems of iron toxicity is often encountered in these soils since the initial increase in Fe content due to submergence is maintained throughout the period of flooding. Thus the high level of Fe^{2+} maintained in the soil and water, coupled with low base status makes the situation alarming due to severe yield decline (Thampatti *et al.* 2005). The poor drainage condition and lack of tidal flushing might have enabled most of the Fe to remain in soluble form. The quantity of available Fe present is sufficient to cause Fe toxicity in the area and will be more severe during post-monsoon season. Fe toxicity has been reported from 20 ppm onwards (Van Breeman and Moorman 1978). Among the different soil subgroups, the increase in available Fe was the highest for the Aquic Udifluvents and for water soluble Fe, Typic Psammaquents showed the highest increase.

The extractable-Al is very high in Kuttanad soils. The Al saturation of total and effective CEC in these soils is also very high and they are above the critical limits for rice (Abraham, 1984). Both the extractable and water soluble Al, showed a considerable increase during the post monsoon period. The increase in acidity might have enhanced the solubility of Al, which is responsible for its increase (Table 4). For Al, the highest values for extractable and water soluble forms were recorded in Aquic Udifluvents.

In general the different fractions of Mn showed a decrease during post monsoon period. Compared to Fe, Mn is present in negligible quantity. The decrease was most conspicuous in Typic Psammaquents for available Mn and Aquic Udifluvents for water soluble Mn.

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