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Spatial and Temporal Variation of Chemical Properties in Different Land Uses of Acid Saline *Pokkali* Soils, Kerala

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ABSTRACT

An investigation was conducted to understand the temporal and spatial variation of available nutrients in acid saline *Pokkali* soils of Kerala. Soil samples were subjected for characterization with respect to chemical parameters such as pH, EC, organic carbon, total N, available P, K, Ca, Mg, S, Zn, Cu, Fe, Mn and B. An increasing trend of soil pH from June to October (low saline phase) and then decreasing trend towards the month of April (high saline phase) was observed. Electrical conductivity showed opposite trend of variation in soil pH. Total Nitrogen, available P and K were high and all the secondary and micronutrients were reported as sufficient. Spatial and temporal variation of all the nutrients was significantly evident except for organic carbon and total nitrogen.

***Key words*:** *Pokkali* soil, Land uses, Sufficiency, Deficiency, Seasonal variation

The *Pokkali* tract (*Typic sulfaquents*) represents the low lying coastal saline areas, situated near the estuaries of streams and rivers not far from the sea, and extends from 9°00 to 10°40’N Latitude and 76°00’ to 77°30’ E Longitude where no other type of agriculture would ordinarily be possible other than cultivation of *Pokkali* rice [1]. This is due to the frequent ingression of tidal water from the sea and result in perennial problems of salinity and high acidity. But these *Pokkali* lands are reported to be high in fertility status and hence manuring is not required for this farming system. The major land uses present in the *Pokkali* tracts are paddy alone, paddy-shrimp, shrimp alone, mangroves and fallow land. The rice cultivation is carried out in *Pokkali* tract during June to early November when the fields are in low saline phase and shrimp farming takes over from mid-November to mid-April (high saline phase).

Only very few studies have been executed on nutrient status in *Pokkali* soil. [2] reported high content of organic carbon, available nitrogen, phosphorus and potassium. She also observed sufficiency of available calcium, sulphur, zinc, copper, iron, manganese and boron whereas magnesium was reported to be deficient. Deficiencies of phosphorus, micronutrients and poor nutrient status in *Pokkali* soil [3]. [4] reported sufficiency of magnesium in *Pokkali* tract and [5] noticed copper deficiency in all the land use systems. Till now, a detailed study of seasonal changes in available nutrient content in *Pokkali* soil is lacking altogether to compensate which the present study has been undertaken to unravel the spatial and temporal variations on chemical characteristics of *Pokkali* soil.

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MATERIALS AND METHODS

The study area falls under agro ecological unit 5 i.e., *Pokkali* land. Soil samples were collected bimonthly from June to April during 2017-18 from five different land uses of *Pokkali* tract viz. paddy-shrimp (N 10°03.310' lat. and E 076°14.986' long.), shrimp alone (N 10°03.821' lat. and E 076°15.239' long.), mangrove (N 10°03.502' lat. and E 076°14.890' long.) and fallow land (N 10°03.869' lat. and E 076°15.348' long.) from Kadamakudy, and paddy alone land use (N 09°58.438' and E 076°19.395' long.) from RRS-Vyttila. A total of 30 soil samples were subjected to characterization keeping the moisture status as in field following wet analysis with respect to chemical properties. Moisture content of the wetland soil samples were estimated gravimetrically. Soil samples were weighed (W_1) and kept in the hot air oven at a temperature of 105°C until a constant weight had been achieved. Then, the samples were weighed (W_2) again and the percentage moisture content (%) was calculated using the equation:

$$\text{Per cent moisture content (\%)} = [(W_1-W_2)/W_1] \times 100.$$

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The soil properties analyzed were pH, electrical conductivity, redox potential, organic carbon, total nitrogen, available phosphorus, available magnesium, available calcium, available potassium, available Sulphur and available micronutrients (Zn, Cu, Fe, Mn and B). The pH of 1:2.5 soil water suspensions was estimated using a pH meter [6]. Electrical conductivity was measured in the soil water suspension (1:2.5) used for pH estimation using a conductivity meter [6]. In situ redox potential of the wetland system was recorded with the redox meter (Model RM 1K TOA). Organic carbon of the soil was estimated by wet digestion method [7-8]. Total nitrogen of the soil samples were estimated in CHNS analyzer (Model: Elementar'svario EL cube). Available phosphorus in the soil samples showing acidic pH was extracted using Bray no.1 reagent [9] and soil samples of neutral to alkaline pH was extracted with 0.5 M sodium bicarbonate ($NaHCO_3$) solution [10]. The concentration of phosphorus in the samples was estimated calorimetrically by reduced molybdate ascorbic acid blue colour method [11] using spectrophotometer (Model: Systronics 169). Neutral normal ammonium acetate was used to extract available potassium in the soil samples and potassium content in the extract was estimated by flame photometry [6]. Available calcium and magnesium in the soil samples was extracted using neutral normal ammonium acetate and its content in the extract was estimated by atomic absorption spectrophotometer (Model: Perkin Elmer-PinAAcle 500). Available Sulphur in the soil sample was extracted by using 0.15% $CaCl_2$ solution [12] and estimated by tubidimetry [13] using a spectrophotometer (Model: Systronics 169). Available micronutrients in the soil samples showing acidic pH were extracted using 0.1 M HCl [14] and soil samples of neutral to alkaline pH were extracted with 0.005 M DTPA and 0.01M $CaCl_2.2H_2O$ buffered at pH 7.3 by 0.1 M triethanol amine (TEA) [15]. The filtrate was collected and analyzed for Fe, Cu, Mn and Zn using Atomic Absorption Spectrophotometer (Model: Perkin Elmer-PinAAcle 500). Available boron in soil sample was extracted with hot water [16] and estimated calorimetrically by azomethane –H using spectrophotometer (Model: Systronics169).

The data on characterization of soil samples was statistically analyzed for two factors using SPSS package (version 7.5 for windows XP, SPSS, Chicago, USA).

RESULTS AND DISCUSSION

Electro-chemical properties (pH, EC and redox potential)

Soil pH is a dynamic parameter, with significant spatial [17] and temporal differences [18]. The mean value of soil reaction among the months ranged from 3.87 (April) to 7.58 (October) (Table 1). An increasing trend of soil pH from June (6.41) to October (7.58) was noticed in all the land uses. The neutral pH reported in October can be attributed to the removal of active acidity from topsoil by South West monsoon followed by the continues submergence of the soil. The *Pokkali* soil was extremely acidic particularly in February (4.20) and April (3.87) months might be due to the presence of soluble salt during the high saline phase (December to May). Increased salt concentration in the soil tends to decrease pH by forcing exchangeable H^+ ions into the soil solution [19]. Direct addition of Na^+ saline solution resulted in an exchange of Na^+ ion with H^+ and Al^{3+} ions, causing acidification [20]. Earlier studies in lowland soils and sediments have reported a decrease in pH with increasing salt concentration [21]. The acidic pH reported in RRS-Vyttila in the initial stage of the crop and during high saline phase can be explained by the oxidation of sulphide compounds in the soil due to aerated condition of the field. Spatial variation in soil reaction was found to be non-significant.

Table 1 Spatial and temporal variation of pH

Land use	Months						Mean
	June	August	October	December	February	April	
Paddy - Shrimp	6.84	2.02	2.23	2.40	5.64	6.05	4.20
Shrimp alone	5.13	5.84	1.52	2.26	5.64	7.87	4.71
Mangrove	7.84	5.97	4.21	3.06	8.39	8.81	6.38
Fallow	2.09	1.55	1.38	1.75	5.16	5.33	2.88
Paddy alone	6.84	2.02	2.23	2.40	5.64	6.05	4.20
Mean	4.987	3.380	2.210	2.102	5.728	6.214	-
CD (0.05)	Months			0.810			
	Locations/Land use			0.740			
	Interaction			1.812			

Table 2 Spatial and temporal variation of electrical conductivity (d Sm^{-1})

Land use	Months						Mean
	June	August	October	December	February	April	
Paddy - Shrimp	6.84	2.02	2.23	2.40	5.64	6.05	4.20
Shrimp alone	5.13	5.84	1.52	2.26	5.64	7.87	4.71
Mangrove	7.84	5.97	4.21	3.06	8.39	8.81	6.38
Fallow	2.09	1.55	1.38	1.75	5.16	5.33	2.88
Paddy alone	6.84	2.02	2.23	2.40	5.64	6.05	4.20
Mean	4.987	3.380	2.210	2.102	5.728	6.214	-
CD (0.05)	Months			0.810			
	Locations/Land use			0.740			
	Interaction			1.812			

Electrical conductivity in soil-water system is a measure of concentration of soluble salts and it imply the extent of salinity in the soil. The highest electrical conductivity was observed in April (6.21 dS m^{-1}) and lowest was in October (2.21 dS m^{-1}) (Table 2). *Pokkali* lands are situated below mean sea level and continuous inundation of sea water into the field caused high electrical conductivity in February and April (high saline phase). From June to October, the electrical conductivity decreased due to the dilution of soluble salt in water by South West monsoon. Among land uses, mangrove (6.38 d Sm^{-1}) was reported with highest electrical conductivity whereas paddy-shrimp land use registered with lowest value (4.20 dS m^{-1}) of electrical conductivity.

Table 3 Spatial and temporal variation of redox potential (mV)

Land use	Months						Mean
	June	August	October	December	February	April	
Paddy - Shrimp	-220	-240	-250	-210	-200	-200	-220
Shrimp alone	-240	-280	-260	-220	-210	-200	-240
Mangrove	-250	-260	-270	-280	-250	-220	-250
Fallow	-240	-280	-310	-280	-250	-210	-240
Paddy alone	160	-220	-300	-250	-160	320	160
Mean	-158	-256	-278	-248	-214	-102	-
CD (0.05)	Months			1.557			
	Locations/Land use			1.422			
	Interaction			3.483			

Table 4 Spatial and temporal variation of organic carbon (%)

Land use	Months						Mean
	June	August	October	December	February	April	
Paddy - Shrimp	3.34	3.45	2.06	1.99	2.12	2.14	2.52
Shrimp alone	2.99	1.69	1.45	1.98	2.79	3.34	2.37
Mangrove	2.84	3.03	3.52	2.89	3.41	3.38	3.18
Fallow	2.62	3.64	2.98	3.17	2.45	2.63	2.92
Paddy alone	3.01	3.52	3.23	2.45	2.59	2.41	2.87
Mean	2.96	3.066	2.648	2.496	2.672	2.78	-
CD (0.05)	Months			NS			
	Locations/Land use			NS			
	Interaction			NS			

Redox potential (Eh) is the single electrochemical property that serves to distinguish a submerged soil from a well-drained soil. Redox potential showed a decreasing trend towards October (-278 mV) and increased from December (-248 mV) to April (-102 mV) (Table 3). The gradual decrease in the redox potential of lowland soil from June (-158 mV) to October (-278 mV) might be due to the reduction of Fe^{3+} and Mn^{4+} resulted from the continuous submergence of the soil. Reduction of soil is a consequence of anaerobic respiration by soil bacteria, and the source of energy is the organic matter. It should be pointed out that *Pokkali* soil has very high value of organic matter content and high in Fe and Mn components. The increase in the redox potential in February and April can be related to high salinity and low soil pH reported in these months. This salinity effect is likely due to a direct influence of the ionic strength and a depression effect on the biological activities of the soil micro-organisms [22]. The hydrogen ion concentration affects Eh values by direct participation in the oxidation- reduction or by affecting the dissociation of oxidants and reductants [23]. The positive values of redox potential measured in April (320 mV) at RRS, Vyttila indicated completely air-dried soil after harvesting of *Pokkali* rice and decrease in this positive value to 160 mV in June can be related with the waterlogged condition resulted from the S-W monsoon. The highest mean value of redox potential was observed in paddy alone land use in RRS, Vyttil (160 mV). It might be due to oxidized condition of field during June and April.

Table 5 Spatial and temporal variation of total nitrogen (%)

Land use	Months						Mean
	June	August	October	December	February	April	
Paddy - Shrimp	0.14	0.13	0.18	0.15	0.18	0.14	0.153
Shrimp alone	0.19	0.18	0.19	0.16	0.1	0.18	0.167
Mangrove	0.14	0.15	0.22	0.18	0.13	0.19	0.168
Fallow	0.18	0.15	0.12	0.16	0.19	0.17	0.162
Paddy alone	0.15	0.14	0.19	0.15	0.21	0.18	0.17
Mean	0.16	0.15	0.18	0.16	0.16	0.17	-
CD (0.05)	Months			NS			
	Locations/Land use			NS			
	Interaction			NS			

Organic carbon

Organic carbon is an index of soil fertility considering the availability of nutrients from organic matter. *Pokkali* soil showed high status of organic carbon (>1.5%) ranged from 2.37 to 3.18% and from 2.49 to 3.06% among the land uses and months respectively (Table 4). This high organic carbon percentage reported in *Pokkali* soil might be due to deltaic deposition of organic matter. Significant spatial and temporal variation in organic carbon was absent.

Table 6 Spatial and temporal variation of available phosphorus (mg kg^{-1})

Land use	Months						Mean
	June	August	October	December	February	April	
Paddy - Shrimp	55.15	165.76	198.40	149.59	143.36	131.33	140.60
Shrimp alone	25.11	45.17	54.95	49.59	42.94	35.89	42.28
Mangrove	50.20	50.58	99.12	86.17	26.13	27.15	56.56
Fallow	37.71	93.90	126.18	121.70	31.55	29.12	73.36
Paddy alone	47.78	85.30	106.21	108.79	107.42	92.36	91.31
Mean	43.189	88.142	116.972	103.170	70.280	63.169	-
CD (0.05)		Months			23.674		
		Locations/Land use			21.611		
		Interaction			NS		

Primary nutrients

Total nitrogen also followed the same trend as organic carbon in all the land uses. Total nitrogen ranged from 0.15 to 0.18% and 0.14 to 0.19% among the months and land uses respectively (Table 5). More than 95% of nitrogen in soils exists in organic form associated with organic matter. This might be the reason for the absence of temporal and spatial variation in total nitrogen in *Pokkali* soil.

Available phosphorus, the second primary nutrient was high (>24 kg ha^{-1}) in all the soil samples irrespective of land uses. The mean value ranged from 43.189 (June) to 116.972 kg ha^{-1} (October) (Table 6). It might be due to the elevation of soil pH from acidic to neutral by the continuous submergence of the soil. A sudden decrease in available phosphorus from December (103.17 kg ha^{-1}) to April (63.16 kg ha^{-1}) might be due to decreasing soil pH towards the month of April. There is all possible reason to believe the occlusion of phosphorus during precipitation of hydrous oxides of iron and aluminium at lower soil pH [4]. Among land uses, paddy-shrimp showed highest available P (140.60 kg ha^{-1}).

Being the third primary nutrient, available potassium was high (>275 kg ha^{-1}) in all the land uses. The decrease in available potassium from June (936.61 kg ha^{-1}) to October (729.43 kg ha^{-1}) (Table 7) can be related to rainfall pattern. South West monsoon during low saline phase (June to October) caused the leaching losses of available potassium. Available potassium increased from December (1032.10 kg ha^{-1}) to April (1216.92 kg ha^{-1}) might be due to incursion of sea water into the field [24]. The least and highest available K was observed in fallow land and shrimp alone land uses respectively.

Table 7 Spatial and temporal variation of available potassium (mg kg^{-1})

Land use	Months						Mean
	June	August	October	December	February	April	
Paddy - Shrimp	881.48	930.00	739.00	1342.47	1347.18	1492.28	1122.07
Shrimp alone	1514.50	1380.12	1334.23	1699.00	1741.00	1702.32	1561.86
Mangrove	1124.79	974.87	723.19	900.10	986.22	1237.84	991.17
Fallow	524.97	322.82	377.14	362.01	657.41	616.48	476.80
Paddy alone	881.48	930.00	739.00	1342.47	1347.18	1492.28	1122.07
Mean	936.617	815.379	729.431	1032.107	1138.812	1216.922	-
CD (0.05)		Months			89.322		
		Locations/Land use			81.539		
		Interaction			199.729		

Secondary nutrients

Being the secondary nutrients, sufficient amount of calcium (>300 mg kg^{-1}) and magnesium (>120 mg kg^{-1}) were recorded in all the land uses. Among the months available calcium and magnesium ranged from 737.99 (June) to (1144.38 mg kg^{-1}) and 642.17 mg kg^{-1} (June) to 1304.51 mg kg^{-1} (February) respectively (Table 8-9). These elements were very high during high saline phase (December to April) compared to low saline phase. This might be attributed to saline water intrusion into the field during high saline phase. Soluble salts in the form of $CaSO_4$, $CaCl_2$, $MgSO_4$, $MgCl_2$ etc. in the sea water made very high quantity of Ca and Mg in *Pokkali* soil during high saline phase. Among the land uses, available calcium and magnesium ranged from 503.16 (fallow land) to 1422.23 mg kg^{-1} (mangrove) and 747.67 (fallow) to 1432.90 mg kg^{-1} (mangrove) respectively.

Available Sulphur was reported as sufficient (>10mg kg^{-1}) throughout the seasons in *Pokkali* soil. Available Sulphur ranged from 1689.9 (October) to 3389.86 mg kg^{-1} (April) across the months and 1921.35 (fallow) to 3428.10 mg kg^{-1} (paddy-shrimp) among the land uses (Table 10). The decrease in available S from June to October can be related to the leaching losses due to S-W monsoon. And also, the lowest redox potential value identified during October (Table 3) pointed towards the possibility of formation of insoluble forms of sulphide compounds. Saline water intrusion into the field during high saline phase caused very high values of available Sulphur in February and April.

Micronutrients

The available micronutrients Zn, Cu, Fe and Mn showed a decreasing trend from June to October and later an increasing trend toward the month of April. The highest values of available Zn (Table 11), Cu (Table 12), Fe (Table 13) and Mn (Table 14) were reported as 57.99 mg kg^{-1}, 2.241 mg kg^{-1}, 135 mg kg^{-1} and 6.18 mg kg^{-1} respectively across the seasons. Available copper was non-significant among the land uses.

Available Zn (215.00 mg kg^{-1}), Fe (2906.43 mg kg^{-1}) and Mn (15.43 mg kg^{-1}) were reported the highest values in paddy-shrimp land use. The solubility of these micronutrients in soils is highly pH depended and increased by decreasing soil pH. This variation in available Zn, Cu, Fe and Mn with respect to soil pH was clearly evident in *Pokkali* soil. A low pH or low Eh favours the reduction of insoluble iron and manganese oxides and increases the solubility [25].

Table 8 Spatial and temporal variation of available calcium (mg kg^{-1})

Land use	Months						Mean
	June	August	October	December	February	April	
Paddy - Shrimp	1107.14	1049.14	929.40	1403.68	1400.88	1182.54	1178.80
Shrimp alone	704.77	579.84	474.86	899.96	1293.91	1486.21	906.59
Mangrove	1183.88	1333.84	1535.03	1565.24	1620.49	1294.88	1422.23
Fallow	367.60	472.36	406.78	550.72	640.76	580.73	503.16
Paddy alone	326.59	508.48	648.31	632.29	765.86	881.15	627.11
Mean	737.996	788.732	798.876	1010.378	1144.384	1085.102	-
CD (0.05)	Months			142.524			
	Locations/Land use			130.106			
	Interaction			318.694			

Table 9 Spatial and temporal variation of available magnesium (mg kg^{-1})

Land use	Months						Mean
	June	August	October	December	February	April	
Paddy - Shrimp	856.21	1131.24	1467.2	1016.21	1503.62	1368.41	1223.83
Shrimp alone	820.14	945.06	594.74	1101.18	1699.24	1077.37	1039.62
Mangrove	910.24	1271.42	1584.2	1654.23	1546.04	1631.24	1432.90
Fallow	508.64	779.86	709.58	577.36	993.67	916.94	747.67
Paddy alone	115.64	694.79	593.22	982.54	780.01	1380.26	757.74
Mean	642.17	964.47	989.80	1066.30	1304.51	1274.84	-
CD (0.05)	Months			141.743			
	Locations/Land use			129.393			
	Interaction			316.947			

Table 10 Spatial and temporal variation of available sulphur (mg kg^{-1})

Land use	Months						Mean
	June	August	October	December	February	April	
Paddy - Shrimp	2511.03	2656.12	2060.76	3351.21	4886.90	5102.60	3428.10
Shrimp alone	2259.95	2452.13	1329.64	2305.23	2686.99	2536.37	2261.72
Mangrove	2891.57	2568.03	2495.62	2585.32	3539.56	3899.83	2996.65
Fallow	2858.58	1705.32	1251.32	1104.23	2247.85	2360.80	1921.35
Paddy alone	2601.08	2108.54	1312.45	1460.56	2008.37	3049.74	2090.12
Mean	2624.44	298.02	1689.95	2161.31	3073.93	3389.86	-
CD (0.05)	Months			250.494			
	Locations/Land use			228.668			
	Interaction			560.121			

Table 11 Spatial and temporal variation of available zinc (mg kg^{-1})

Land use	Months						Mean
	June	August	October	December	February	April	
Paddy - Shrimp	215.00	128.72	122.97	196.66	228.72	275.14	215.00
Shrimp alone	111.44	74.00	28.48	78.42	312.25	413.45	111.44
Mangrove	181.83	143.80	104.45	126.83	287.57	376.75	181.83
Fallow	93.05	68.11	17.17	88.05	133.40	160.76	93.05
Paddy alone	24.08	24.35	16.93	28.84	33.23	34.36	24.08
Mean	125.080	87.796	57.999	103.760	199.035	252.091	-
CD (0.05)	Months			1.253			
	Locations/Land use			1.144			
	Interaction			2.802			

Table 12 Spatial and temporal variation of available copper (mg kg^{-1})

Land use	Months						Mean
	June	August	October	December	February	April	
Paddy - Shrimp	2.35	3.83	2.62	2.54	3.41	4.23	3.16
Shrimp alone	5.04	6.10	2.30	1.97	4.14	6.00	4.26
Mangrove	3.68	2.68	3.15	3.69	4.55	7.53	4.21
Fallow	4.45	2.51	1.31	1.67	4.65	4.74	3.22
Paddy alone	6.30	5.25	1.82	2.40	8.93	7.35	5.34
Mean	4.364	4.075	2.241	2.454	5.137	5.971	-
CD (0.05)	Months				1.246		
	Locations/Land use				1.137		
	Interaction				NS		

Table 13 Spatial and temporal variation of available iron (mg kg^{-1})

Land use	Months						Mean
	June	August	October	December	February	April	
Paddy - Shrimp	2623.23	2688.88	2367.06	3158.53	3234.00	3366.86	2906.43
Shrimp alone	1915.50	1791.30	1103.47	2230.00	2003.35	2269.57	1885.53
Mangrove	2796.69	2110.21	1259.00	2362.97	2784.01	3551.01	2477.32
Fallow	1331.03	1252.22	1066.00	1716.00	1827.51	1969.15	1526.99
Paddy alone	1298.95	1200.21	956.15	1452.96	1569.32	1855.00	1388.77
Mean	1993.08	1808.56	1350.33	2184.09	2283.63	2602.31	-
CD (0.05)	Months				105.26		
	Locations/Land use				96.09		
	Interaction				235.37		

Table 14 Spatial and temporal variation of available manganese (mg kg^{-1})

Land use	Months						Mean
	June	August	October	December	February	April	
Paddy - Shrimp	14.34	15.66	11.83	11.93	19.90	18.91	15.43
Shrimp alone	13.41	7.89	3.63	7.38	13.97	22.97	11.54
Mangrove	16.60	14.72	4.87	5.87	17.82	21.66	13.59
Fallow	12.67	10.51	8.52	12.21	11.89	13.05	11.48
Paddy alone	7.41	9.25	2.07	10.18	14.98	14.55	9.74
Mean	12.88	11.60	6.18	9.51	15.71	18.22	-
CD (0.05)	Months				1.252		
	Locations/Land use				1.143		
	Interaction				2.801		

Table 15 Spatial and temporal variation of available boron (mg kg^{-1})

Land use	Months						Mean
	June	August	October	December	February	April	
Paddy - Shrimp	5.97	5.17	6.65	5.94	6.10	7.32	6.19
Shrimp alone	2.19	3.19	3.16	4.99	4.20	6.60	4.06
Mangrove	3.56	3.04	4.98	4.32	5.82	5.34	4.51
Fallow	1.96	2.74	2.18	3.02	5.03	4.81	3.29
Paddy alone	1.51	2.07	2.64	3.62	4.06	5.06	3.16
Mean	3.038	3.242	3.923	4.378	5.041	5.826	-
CD (0.05)	Months				1.103		
	Locations/Land use				1.007		
	Interaction				NS		

Considering the low saline phase, available Zn, Cu, Fe and Mn were found to be decreased from June to October. This reduction in the available Zn can be explained by formation of insoluble compounds like $ZnFe_2O_4$ (franklinite), ZnS (sphalerite), $ZnCO_3$ (smithsonite) and Zn $(OH)_2$ due to continuous submergence of *Pokkali* soil. Adsorption of soluble Zn^{2+} ion on oxides minerals also could decrease the Zn availability in soil. The dominant form of Cu at pH 7 is $CuOH^{+}$ which is insoluble. Copper also can be precipitated as CuS and $CuCO_3$ in lowland soil [26]. Reduction in the available Fe can be explained by the precipitation of Fe^{2+} as $FeCO_3$ and Fe-S compounds. High organic matter (>0.75%) in *Pokkali* soil also enhanced the rate of reduction of iron. Neutral pH conditions also promote the precipitation of poorly ordered Fe minerals like ferrihydrite [27]. The decrease in available Mn from June to October might be due to the precipitation of Mn^{2+} on $MnCO_3$ and $(MnOH)_2$ in the soil solution [22].

Available boron was sufficient (>0.5 mg kg^{-1}) in all the land uses. Available boron registered an increasing trend from June (3.038 mg kg^{-1}) to April (5.82 mg kg^{-1}) where the mean values reported during low saline phase (June- December) were on par with each other (table 15). Available B reported during high saline phase (4.37 to 5.82 mg kg^{-1}) was higher than low saline phase (3.03 to 3.92 mg kg^{-1}) which pointed towards the marine influence on *Pokkali* land during high saline phase.

CONCLUSION

The effect of spatial and temporal variations could be very clearly visualized on electrochemical properties and status of all nutrients except organic carbon and total nitrogen whereas, direct effect of land uses on soil properties was not identified. Saline water intrusion into the *Pokkali* fields from Arabian Sea during December to April (high saline phase) caused significant increase in electrical conductivity, available Ca, Mg, S and K. The decrease in pH in February and April increased the availability of nutrients viz., Zn, Cu, Fe and Mn. Available phosphorus and boron were high in the month of October where neutral pH was recorded. Further trials are essential to arrive at the impact of land uses on soil properties.

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