



Forms and Distribution of Soil Acidity in at Surface and Sub-surface Soils under Different Landforms and Land Uses, Tropical Humid Region, India

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ABSTRACT

Background: In soils of the humid tropics, acidity is a major natural threat. To know the forms and distribution of soil acidity on surface and sub-surface soil depths in different landforms and land uses, a study was conducted in the Elamdesam block, Idukki district, Kerala.

Methods: Soil samples from 28 profiles across various landforms and land uses were analysed for water extractable acidity, KCl extractable H and Al and BaCl₂ acidity. Six profiles from uplands and lowlands from different land uses were taken and aluminium saturation was determined.

Result: Soils are extremely acidic to moderately and strongly acidic. KCl exchangeable H ranged from 0.17 to 2.45 at the surface and up to 3.19 meq/100 g in the subsoil. KCl exchangeable Al ranged from 0.22 to 0.96 at the surface and up to 1.73 meq/100 g in the subsoil. BaCl₂ acidity ranged from 1.65 to 23.27 at the surface and up to 26.60 meq/100 g in the subsoil. KCl exchangeable (H+Al) ranged from 0.66 to 2.89 at the surface and 0.07 to 3.55 meq/100 g in the subsoil. Al saturation ranged from 13.80 to 43.52 at the surface and up to 70.92 per cent in the subsoil. Soils of uplands had more exch. H, exch. Al, exch. (H+Al) and BaCl₂ acidity than lowlands. Among land uses, rubber plantation has more exch. H, exch. Al, exch. (H+Al) and BaCl₂ acidity and aluminium saturation. To ameliorate soil acidity effectively, the application of burnt lime to the soil surface and gypsum to the subsoil has been recommended as part of sustainable land management practice.

Key words: Aluminium saturation, Exchangeable acidity, Land use, pH-dependent acidity, Sub-soils, Total potential acidity.

INTRODUCTION

The factors of soil acidity in tropical humid regions are leaching of bases due to heavy rainfall, acidic parent material (rhyolite and granite, quartzite, schist, etc.), organic matter decay and release of organic acids, the harvest of high-yielding crops and presence of alumina-silicate minerals, conversion of native forest and range land into cultivated land, external inputs of acid-forming chemical fertilizers and inappropriate agriculture practices, the low buffer capacity of the soil due to low activity clay results in the acidity of the soil both at the surface and on sub-surface. 30% of global land and 50% of global arable land are affected by acidification (Abubakar *et al.*, 2024). In India, around 90 m ha of area is having soil acidity threat and 34.5 per cent of cultivated lands are acidic in reaction. Further, about 25 m ha area was critically degraded due to pH <5.5. Crop production affected 50 per cent of the world's arable land due to soil acidity may be subjected to the effect of aluminium (Al) toxicity, of which 60 per cent of the acid soils in the world belong to the tropics and subtropics. However, aluminium toxicity is a common soil acidity which limits crop production caused by heavy rainfall (3911 mm per annum) and leaching of bases (< 50% base saturation) from both surface and sub-surface through the eluviation and illuviation process, resulting in the formation of low-fertility Ultisols. Subsoil acidity is a major constraint in hot,

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humid, tropical climatic regions, as it causes high content of soluble Al (aluminium toxicity) and Mn or low plant-available P, Mo, Ca, Mg and K, inhibiting physiological and biological activities, root development and uptake of nutrients such as P, Ca, Mg, K and Mo as well as water and causes disease to crops and also affects crop quality (Nair *et al.*, 2019). Thus, soil pH below 5.5 needs major

emphasis for amelioration. Sub-surface acidity is more problematic than surface soil acidity due to its difficult nature of amelioration at lower soil depths and also, liming takes several years to increase the pH in the sub-surface layers. The study objectives are i) to know the different forms and distribution of acidity at the surface and on sub-surface soils at different depths, ii) to know the different forms and distribution of acidity at the surface and sub-surface soils under different landforms and land uses and iii) to know the management options to ameliorate surface and subsurface acidity.

MATERIALS AND METHODS

Study area details

The present investigation was conducted at ICAR-National Bureau of Soil Survey and Land Use Planning, Regional Centre, Hebbal, Bangalore during 2014-2017. The study area was Elamdesam block, Thodupuza taluk, Idukki district, Kerala (total geographical area of 29,127.16 ha: cultivable land- 18750.48 ha and forest- 8256.48 ha) lying between north latitudes 9° 46' 38.2" and 10° 2' 18.14" and east longitudes 76° 42' 59.49" and 76° 53' 46.99" falls under hot, wet and sub-humid to humid ecoregion of the central and southern Sahyadris (AESR 19.2). It is divided into seven panchayats. The mean annual rainfall varies from 3462 to 3602 mm with the Ustic soil moisture regime and the mean annual temperature varies between 21°C to 27°C with the Iso hyperthermic soil temperature regime. The length of the dry period is two to two and a half months (Fig 1). The main rocks encountered are charnockites and granite gneiss. The landform of the block is the Western Ghats (>600 m MSL) with exposed rocks, high hills (300 to 600 m MSL), foothills and midland (30 to 300 m MSL) and lowlands (submerged paddy land) and valley plain. Elevation ranges from 30 m to 850 m. Ultisols, Inceptisols and Alfisols are the major soils encountered in the block.

Soil sampling and laboratory characterization

The detailed soil survey was carried out at a 1:10,000 scale and 28 master profiles horizon-wise samples were analysed for physicochemical parameters including different forms of soil acidity and pH, out of which six selected pedons from uplands and lowlands from different land uses viz., mixed plantation (coconut, areca nut, banana, mango and teak), oil palm, rubber and paddy were analysed for different forms of acidity viz., pH on 1:2.5 water, KCl exchangeable H, KCl exchangeable Al, barium chloride extractable acidity in a laboratory using standard procedures (Table 1). Calculated KCl exchangeable (H+Al), base saturation (equation 1) and aluminium saturation (equation 2).

$$\text{Base saturation (\%)} = \frac{\text{Total bases}}{\text{CEC}} \times 100 \quad \dots (1)$$

$$\text{Aluminium saturation (\%)} = \frac{\text{Extracted Al}}{\text{Exchangeable Ca + Mg + K + Na + extracted Al}} \times 100 \quad \dots (2)$$

Where exchange Ca, Mg, K, Na, total bases, CEC and extractable Al are in c mol (p+) kg⁻¹ soil.

RESULTS AND DISCUSSION

Morphological properties in soils of different landforms and land uses

Morphological properties of soils of the Elamdesam block (Table 2) shows that soil depth varied from shallow (0-34 cm) in oil palm land use to very deep (0-210 cm) in upland mixed plantations. Variations in soil depth due to variations in physiography, temporal changes in transportation, accumulation of alluvium by wind and water, erosion and the addition of organic litter resulted in different depths in different landforms and land uses. All the pedons from different landform systems and land uses found on the Bt horizon shows sufficient eluviation and illuviation of clay occurred, resulting in surface clay transported and

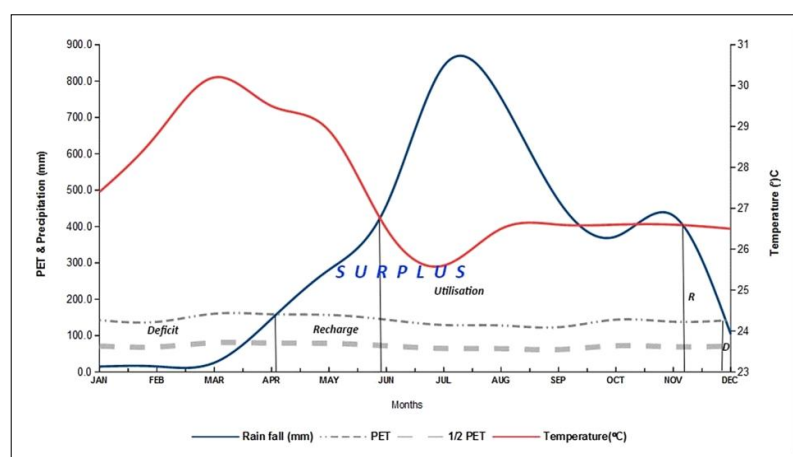


Fig 1: Water balance diagram of the Elamdesam block, tropical humid region, Kerala.

deposited in the sub-surface, also indicated by the presence of patchy thin clay cutans. Soil colour varied from yellowish red (5YR 5/6) to dark reddish brown (5YR3/3), dark brown (7.5YR3/2), brown (7.5YR 4/4) and dark brown (7.5YR 4/3; 10YR4/3) at the surface. Variation in soil colour due to parent materials, oxidation and reduction of parent materials due to variation in temperature, alternate wetting and drying due to rainfall and waterlogging and organic materials addition and decomposition impart different soil colours. Soil structure varied from weak to moderate, medium sub-angular blocky, which holds a low water content during the cropping period. Soil consistency varied from friable to firm, slightly sticky to sticky and slightly plastic to plastic in nature. Generally, upland soils were non-gravelly to gravelly (<35 per cent) due to the occurrence of slight to moderate erosion.

Physicochemical properties in soils of different landforms and land uses

Physicochemical properties (Table 3) indicated that, among particle size classification, sand was a dominant fraction which recorded 45.48-61.65 at the surface to 17.91-57.38 per cent in the sub-surface followed by clay content, recorded 21.03-41.60 at surface to 25.44-63.52 per cent in sub-surface and silt was the lowest fraction (10.79-17.32 in at surface to 9.98-23.43 per cent in sub-surface). Hence, the texture of these soils was sandy clay to sandy clay loam and clay. Generally, sub-surface recorded higher clay content than the surface due to the illuviation process, followed by upward movement of coarser particles and Bt horizon as reported above in morphological properties. However, clay is higher but is low-activity clay, having kaolinite, goethite, gibbsite and hydroxyl interlayered vermiculites as major minerals in their clay fraction (Chandran *et al.*, 2005 and Nair *et al.*, 2019).

Organic carbon content was generally high both in uplands and lowlands in different land uses, which ranged from 1.19-3.39 in at the surface to 0.51-3.23 per cent in the sub-surface. High organic carbon content was due to the addition of more organic matter through leaf litter and plant biomass from plantations and rubber, paddy straw and

root left over and their decomposition, coupled with minimum or zero tillage, added high organic carbon content. However, surface soils have higher organic carbon content and it declines with depth due to the addition and accumulation of organic matter that occurred on the soil surface rather than the sub-surface. Soils are non-saline recorded electrical conductivity <2.0 indicate lower soluble salts, which was due to the intense leaching was occurred by high rainfall and freely draining salts in soils. Among exchangeable bases, exchangeable calcium was recorded as higher, followed by magnesium and followed the trend $\text{exch. Ca} > \text{exch. Mg} > \text{exch. K} > \text{exch. Na}$. Lower bases were due to heavy leaching and to the excessively well-drained nature of soils (Bandyopadhyay *et al.*, 2018). Cation exchange capacity was low, recorded 5.94-15.12 in at the surface to 2.48-16.22 cmol (p+) kg^{-1} in the subsoil. However, rubber land use recorded more CEC, followed by paddy and oil palm land use. The low CEC of soils was due to the presence of low-activity clay mineral kaolinite and the comparatively higher CEC in surface soils than subsoils was due to organic colloids. Base saturation was <35 per cent (7.52-29.58 in at surface to 3.51-40.71 per cent in subsoil), hence soils belong to Ultisols and due to low bases and low nutrient reserves, higher slope limits the agricultural crop production in the Elamdesam block in a tropical humid region.

Different forms and distribution of soil acidity and aluminium saturation in different landforms and land uses and their interrelationship

Forms and distribution of soil acidity (Table 4) shows that soil reaction was extremely acidic (pH: 4.44) to strongly acidic (pH: 5.22) at the surface, to extremely acidic (pH: 4.16) to moderately acidic (pH: 5.68) in the subsoil. Low pH was due to high organic matter in soils of higher elevations, which generated pH-dependent charges. pH was positively and significantly correlated with base saturation ($r^{++} = 0.45$) and significantly negatively correlated with CEC ($r^{++} = -0.47$), ex. Al ($r^{+++} = -0.60$) and Al- saturation ($r^{+++} = -0.55$) (Fig 2), indicating that heavy rainfall resulted in the removal of exchangeable bases and low activity clay

Table 1: Methods of soil analysis.

Parameter	Method	Reference
Particle size analysis	International pipette method	Piper, 1966
Soil pH and electrical conductivity	1:2.5 soil: water ratio	Jackson, 1973
Organic carbon	The Walkley and Black (1934) method	Walkley and Black, 1934
Cation exchange capacity	NN ammonium acetate method	Schollenberger and Dreiblebis, 1930
Exchangeable bases	NN ammonium acetate method and atomic absorption spectrophotometry	Sparks, 1996
Exch. H and Exch. Al	1 N KCl extraction and titration with standard alkali	Jackson, 1973
BaCl ₂ acidity	Barium chloride-Tri ethanol amine solution buffered at pH 8.2	Hesse, 1971
pH-dependent acidity	By deducting exchangeable acidity (H+Al) from total potential acidity	Coleman and Thomas, 1967

and its movement to deeper layers of soils resulted in the formation of lower pH. The surface and subsoil acidity can be described in their three different forms, viz., exchangeable acidity (exch. H+Al), pH-dependent acidity (acidity obtained by subtracting exchangeable acidity from total potential acidity or BaCl₂ acidity) and total potential

Table 2: Morphological properties of soils in different landforms and land use systems.

Series	Depth (cm)	Horizon	Colour	Texture	Structure	Consistence	Coarse fragments	Erosion	Special features
Uplands									
Mixed plantation: Coconut, arecanut, cocoa, banana, mango, teak									
Pedon 1: KOD/P22-1									
	0-16	Ap	5YR5/6	sc	m1sbk	fr, s,p	20-25	Moderate	
	16-35	Bt1	5YR5/6	sc	m2sbk	fi, vs,vp	20-25		
	35-57	Bt2	5YR5/6	cl	m2sbk	fi, s,p	20-30		
	57-96	Bt3	2.5YR4/6	c	m2sbk	fi, s,p	10-15		
	96-125	Bt4	2.5YR4/6	cl	m2sbk	fi, s,p	10-15		
	125-151	Bt5	2.5YR4/6	sc	m2sbk	fi, s,p	15-20		
	151-177	Bt6	2.5YR4/6	c	m2sbk	fi, s,p	-		
	177-210+	Bt7	2.5YR3/6	cl	m2sbk	fi, s,p	-		
Oil palm									
Pedon 2: ALK/T8/P1-1									
	0-10	Ap	5YR3/3	scl	m1sbk	fr, ss, sp	30	Moderate	
	10-22	Bt1	5YR4/4	scl	m2sbk	fr, ss,sp	35		
	22-34	Bt2	5YR4/4	scl	m2sbk	fr, ms,mp	40		
Rubber									
Pedon 3: VNP/P2-1									
	0-10	Ap	7.5YR3/2	c	m1sbk	fr, s,p	5-10	Moderate	
	10-30	Bt1	7.5YR3/2	sc	m1sbk	fr, s,p	5-10		TTnP
	30-50	Bt2	7.5YR3/2	sc	m1sbk	fr, s,p	5-10		TTnP
	50-70	Bt3	7.5YR3/3	cl	m1sbk	fr, s,p	5-10		
	70-90	Bt4	7.5YR3/4	cl	m1sbk	fr, s,p	5-10		
	90-110	Bt5	5YR 3/3	cl	m1sbk	fr, s,p	5-10		
	110-150	Bt6	5YR 3/3	cl	m2sbk	fr, ss,sp	20-30		
Pedon 4: ALK P45-1									
	0-17	Ap	7.5YR4/4	scl	m2sbk	fr, s,p	-	Moderate	
	17-36	Bt1	5YR4/4	sc	m2sbk	fr, s,p	-		
	36-58	Bt2	2.5YR4/6	c	m2sbk	fr, s,p			
	58-79	Bt3	2.5YR4/6	sc	m2sbk	fr, s,p	-		
	79-101	Bt4	2.5YR4/6	sc	m2sbk	fr, s,p	10-15		
	101-137	Bt5	2.5YR4/6	sc	m2sbk	fr, s,p	20-30		
Lowlands									
Paddy									
Pedon 5: KAR/ P36-1									
	0-11	Ap	10YR4/3	sc	m1sbk	fr, s,p	-	Slight	
	11-27	Bt1	10YR 4/4	cl	m2sbk	fr, s,p	-	-	
	27-41	Bt2	10YR 4/4	scl	m2sbk	fr, s,p	-	-	
	41-54	Bt3	10YR 4/6	c	m2sbk	fr, s,p	-	-	TTnP
	54-70	Bth	10YR 4/6	c	m2sbk	fr, s,p	-	-	TTnP
	70-81	Btc	10YR 5/6	sc	m2sbk	fr, s,p	-	-	TTnP
	81-95	Btg	10YR 4/1	c	m2sbk	fr, vs,vp	-	-	Gleying
Mixed plantation: coconut, cocoa, banana, arecanut, teak									
Pedon 6: KAR P40-1									
	0-16	Ap	7.5YR4/3	scl	f1sbk	fr, s,p	-	Slight	
	16-36	Bt1	7.5YR4/6	scl	m2sbk	fr, s,p	-		
	36-60	BC	7.5YR4/6	scl	m2sbk	fr, ss,sp	20-25		

Table 3: Physicochemical properties and aluminium saturation in soils of different landforms and land use systems.

Series	Depth (cm)	Particle size distribution (% of <2 mm)			Organic carbon (%)	EC (dS m ⁻¹)	Exchangeable bases cmol (p+) kg ⁻¹				CEC cmol (p+) kg ⁻¹	B.S (%)	Aluminium saturation (%)
		Sand	Silt	Clay			Ca	Mg	K	Na			
Uplands													
Mixed plantation: Coconut, arecanut, cocoa, banana, mango, teak													
Pedon 1: KOD/P22-1													
	0-16	53.42	10.79	35.79	1.59	0.05	0.97	0.12	0.10	0.05	5.94	20.86	15.08
	16-35	47.52	16.84	35.64	1.23	0.02	0.70	0.00	0.04	0.04	4.75	16.53	7.10
	35-57	42.80	17.28	39.92	0.99	0.02	0.42	0.00	0.02	0.03	4.86	9.72	37.20
	57-96	44.59	13.91	41.51	0.91	0.02	0.32	0.00	0.02	0.03	4.10	9.23	38.78
	96-125	44.67	15.87	39.47	0.91	0.02	0.32	0.00	0.02	0.02	4.00	8.96	39.12
	125-151	55.77	6.64	37.59	0.79	0.02	0.11	0.00	0.02	0.02	3.35	4.54	65.61
	151-177	38.89	17.49	43.62	0.59	0.02	0.10	0.00	0.02	0.02	3.78	3.51	64.37
	177-210+	40.75	21.26	38.00	0.51	0.01	0.13	0.00	0.02	0.02	2.48	6.59	50.95
Oil palm													
Pedon 2: ALK/T8/P1-1													
	0-10	61.65	17.32	21.03	2.47	0.07	0.58	0.20	0.18	0.09	10.15	10.37	27.54
	10-22	52.12	19.27	28.60	1.55	0.03	0.17	0.06	0.12	0.05	7.99	4.99	45.26
	22-34	57.41	17.16	25.44	1.11	0.02	0.30	0.01	0.10	0.05	7.34	6.21	44.80
Rubber													
Pedon 3: VNP/P2-1													
	0-10	43.40	15.00	41.60	3.39	0.14	0.60	0.18	0.27	0.09	15.12	7.52	27.89
	10-30	47.77	15.09	37.14	3.07	0.17	0.65	0.11	0.14	0.07	13.18	7.41	33.88
	30-50	46.09	15.32	38.59	3.03	0.11	0.64	0.11	0.10	0.05	13.28	6.82	30.62
	50-70	44.31	18.47	37.22	3.23	0.10	0.58	0.09	0.11	0.07	14.04	6.05	32.57
	70-90	37.68	22.99	39.33	2.06	0.03	0.22	0.05	0.10	0.05	12.74	3.23	51.13
	90-110	36.83	23.43	39.74	2.3	0.03	0.31	0.00	0.13	0.06	13.93	3.58	41.94
	110-150	37.63	22.98	39.39	1.74	0.03	0.31	0.05	0.11	0.04	11.66	4.39	45.63
Pedon 4: ALK/ P45-1													
	0-17	60.08	12.45	27.47	2.05	0.03	1.46	0.14	0.14	0.03	11.02	16.04	35.21
	17-36	45.99	15.80	38.21	1.32	0.03	0.39	0.08	0.09	0.03	10.91	5.41	70.92
	36-58	40.78	15.83	43.40	1.00	0.02	0.45	0.11	0.09	0.11	9.69	7.82	61.28
	58-79	49.58	12.00	38.41	0.84	0.02	0.39	0.12	0.08	0.07	9.38	7.04	62.05
	79-101	46.15	13.12	40.73	0.64	0.01	0.47	0.11	0.08	0.08	8.36	8.76	22.28
	101-137	48.08	14.97	36.94	0.44	0.01	0.70	0.16	0.05	0.07	6.53	15.17	12.38
Lowlands													
Paddy													
Pedon 5: KAR/ P36-1													
	0-11	45.48	16.47	38.05	1.19	0.04	1.86	0.63	0.12	0.07	9.08	29.58	13.80
	11-27	42.63	19.84	37.53	1.39	0.15	1.17	0.15	0.05	0.25	8.57	18.85	43.63
	27-41	47.81	19.24	32.94	1.35	0.08	0.76	0.14	0.03	0.14	7.45	14.37	40.89
	41-54	39.17	19.12	41.71	0.99	0.03	1.72	0.66	0.04	0.05	7.14	34.67	1.98
	54-70	40.48	15.01	44.51	0.8	0.03	1.65	0.85	0.05	0.03	7.55	34.12	1.15
	70-81	47.36	11.53	41.11	0.83	0.03	1.56	0.88	0.07	0.15	6.53	40.71	0.00
	81-95	17.91	18.58	63.52	2.59		1.97	1.09	0.12	0.13	16.22	20.35	34.40
Mixed plantation: Coconut, cocoa, banana, arecanut, teak													
Pedon 6: KAR/ P40-1													
	0-16	52.69	16.95	30.36	1.73	0.10	0.53	0.28	0.24	0.04	9.28	11.74	43.52
	16-36	57.38	9.98	32.64	0.72	0.02	1.05	0.49	0.07	0.04	6.53	25.24	11.78
	36-60	54.85	13.14	32.01	0.48	0.01	1.22	0.65	0.11	0.07	7.14	28.72	6.39

Table 4: Forms and distribution of surface and sub-surface acidity in soils of different landforms and land use systems.

Series	Depth (cm)	pH _w (1:2.5 water)	KCl exch. (H+Al)	KCl exch. H	KCl exch. Al	BaCl ₂ or total potential acidity	pH- dependent acidity
--meq/100 g--							
Uplands							
Mixed plantation: Coconut, arecanut, cocoa, banana, mango, teak							
Pedon 1: KOD/P22-1							
	0-16	5.22	0.39	0.17	0.22	9.02	8.63
	16-35	5.42	0.31	0.25	0.06	7.60	7.29
	35-57	5.11	0.73	0.45	0.28	6.65	5.92
	57-96	4.87	0.63	0.39	0.24	8.07	7.44
	96-125	4.89	0.68	0.45	0.23	6.17	5.49
	125-151	4.85	0.66	0.37	0.29	7.12	6.46
	151-177	4.81	0.46	0.22	0.24	5.70	5.24
	177-210+	5.23	0.17	0.00	0.17	5.70	5.53
Oil palm							
Pedon 2: ALK/T8/P1-1							
	0-10	4.87	1.42	1.02	0.40	17.25	15.83
	10-22	5.02	1.47	1.14	0.33	12.65	11.18
	22-34	5.18	1.42	1.05	0.37	12.08	10.66
Rubber							
Pedon 3: VNP/P2-1							
	0-10	4.44	2.89	2.45	0.44	23.27	20.38
	10-30	4.20	3.43	2.93	0.50	26.60	23.17
	30-50	4.57	2.79	2.39	0.40	15.67	12.88
	50-70	4.81	2.71	2.30	0.41	20.42	17.71
	70-90	4.97	3.30	2.87	0.43	21.85	18.55
	90-110	4.87	3.55	3.19	0.36	20.90	17.35
	110-150	5.00	3.16	2.73	0.43	18.52	15.36
Pedon 4 : ALK/ P45-1							
	0-17	4.9	2.89	0.29	0.96	1.40	-1.49
	17-36	4.55	3.43	0.47	1.44	1.40	-2.03
	36-58	4.78	2.79	0.54	1.20	1.50	-1.29
	58-79	4.89	2.71	0.29	1.08	1.25	-1.46
	79-101	5.22	3.30	0.72	0.21	1.25	-2.05
	101-137	5.35	3.55	0.08	0.14	6.50	2.95
Lowlands							
Paddy							
Pedon 5: KAR/ P36-1							
	0-11	4.88	0.66	0.23	0.43	8.50	7.84
	11-27	4.16	1.67	0.42	1.25	11.00	9.33
	27-41	4.42	0.98	0.24	0.74	4.00	3.02
	41-54	5.30	0.12	0.07	0.05	4.00	3.88
	54-70	5.33	0.10	0.07	0.03	6.00	5.9
	70-81	5.33	0.07	0.07	0.00	4.50	4.43
	81-95	4.77	2.23	0.50	1.73	2.15	-0.08
Mixed plantation: Coconut, cocoa, banana, arecanut, teak							
Pedon 6 : KAR/ P40-1							
	0-16	4.60	1.15	0.31	0.84	1.65	0.5
	16-36	5.58	0.32	0.10	0.22	5.00	4.68
	36-60	5.68	0.50	0.36	0.14	2.40	1.90

acidity (BaCl_2 acidity). Total potential acidity includes both exchangeable acidity and pH-dependent acidity. 1 N KCl exchangeable acidity shows that exch. H recorded higher (0.66-2.89 at surface to 0.07-3.55 meq/100g in sub-surface) than exch. Al (0.22-0.96 in at surface to 0-1.73 meq/100 g in sub-surface). In highly weathered Ultisols in tropical humid regions, alumina silicate minerals, both primary and secondary and Al oxides (gibbsite) were a huge source of Al and their higher specific surface area encourages the formation of soluble and exchangeable Al (Nair *et al.*, 2019). Exchange acidity (H+Al) has a relatively low contribution towards total acidity. As soil pH increased, exchangeable Al decreased and became lowest ($0 \text{ cmol (p+) kg}^{-1}$) at pH 5.33 in paddy lands. Total potential/ BaCl_2 acidity was higher in rubber plantations, followed by oil palm, mixed plantations and paddy land use and it ranged from 1.65-23.27 in at the surface to 1.25-26.60 meq/100 g in the subsoil. Higher total potential acidity in rubber followed by oil palm land use was due to higher organic matter and clay content, resulting in higher organic carbon content thereby resulting in the formation of high pH-dependent acidity (varied from -1.49-20.38 in at surface to -2.05-23.17 meq/100 g in sub-surface). However, the contribution of pH-dependent acidity to total potential acidity was much higher than exchangeable acidity in different landforms and land uses except pedon 4 under rubber plantation which may be due to lower organic carbon content, was due to pedon 4 might have been studied in a newly planted rubber plantation resulted in lesser addition of organic matter recorded lesser pH dependent acidity. Total potential acidity and pH-dependent acidity followed the trend of rubber land use > oil palm land use > mixed plantation > paddy land use. The higher contribution of pH-dependent acidity is attributed to variable charge due to high OC content under plantations and low-activity clays (Bandyopadhyay *et al.*, 2018). The decrease in pH-dependent acidity and total potential acidity with depth was due to a decrease in organic

matter content. Aluminium saturation was higher in subsoil than surface soil, it recorded 13.80-35.21 in at the surface to 0-70.92 per cent in subsoil. A higher content of aluminium significantly leads to phosphorus deficiency because when soil contains high aluminium, phosphate is precipitated at the roots and residues, it affects cell division, reduces the activity during cell wall formation and obstructs phosphorus uptake (Minh *et al.*, 2024). Aluminium saturation followed the trend of rubber plantation > oil palm > mixed plantation > paddy land uses (Table 3) and it significantly negatively correlated with pH ($r^{***} = -0.55$) and base saturation ($r^{***} = -0.80$) and also negatively correlated with pH-dependent acidity ($r = -0.03$) whereas significantly positively correlated with ex. H+Al ($r^+ = 0.36$) and ex. Al ($r^{**} = 0.53$) (Fig 2). CEC has significantly positively correlated with all three forms of acidity and organic carbon ($r^{***} = 0.83$) content, indicating that the better the OC higher the CEC in soil.

Management of surface and sub-surface acidity under different landforms and land uses

Soil acidity and aluminium toxicity in at-surface soils can be ameliorated through liming using ground limestone or calcite (CaCO_3), burnt lime (CaO) or dolomite ($\text{CaCO}_3 \cdot \text{MgCO}_3$), followed by tillage. However, subsoil application of lime by deep ploughing or deep placement is practically not possible and is difficult, particularly in rubber plantations, oil palm plantations and mixed plantations in different landforms. Hence, application of gypsum at the surface is a viable option to ameliorate subsoil acidity as it is partially soluble and percolates down the sub-surface in the leaching regime of high rainfall tropical humid environments, thereby enhancing the labile calcium and decreasing the Al in subsoils. In the study area having Ultisols major soil, replenishment of Al^{3+} from this exchangeable source requires high lime and gypsum requirements @ 5-10 tonnes ha^{-1} for lime and 10-15 tonnes ha^{-1} for gypsum (Nair *et al.*, 2019). Liming can lessen or stop Al^{3+} toxicity in

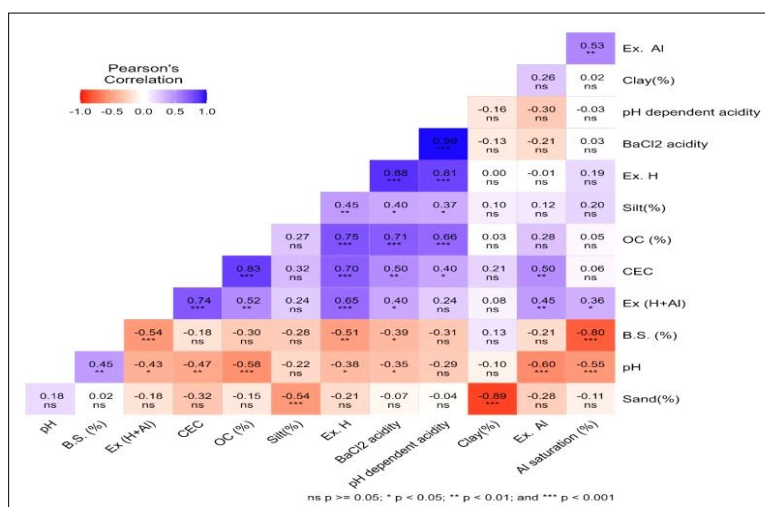


Fig 2: Correlation coefficient (r) among soil properties and forms of soil acidity and aluminium saturation.

moderately active acid sulfate soils (Minh *et al.*, 2024). The application of organic matter to the soil with low organic carbon status soils through manure can also release the cations such as calcium and magnesium during decomposition and can increase the soil pH (Abeje *et al.*, 2024). Application of biochar can also reduce the soil acidity through its addition of basic cations and consumption of H^+ ions present in the soil (Abubakar *et al.*, 2024).

CONCLUSION

Soil acidification is a natural phenomenon in high and heavy rainfall environments such as tropical humid regions, where leaching slowly acidifies the soil over time. Soluble basic salts such as Ca, Mg, K and Na are leached away by drainage water and insoluble acidic residues composed chiefly of oxides and silicates of iron, silicon and aluminium are left, which accumulate in pretty high amounts. These salts are acidic in reaction; hence, the soils are acidic. The study area is the Elamdesam block, a tropical humid region, Kerala, having a major area under rubber plantations, followed by mixed plantations, paddy and oil palm. In these land uses it was reported both surface and subsurface acidity, recorded aluminium saturation of 13.80-35.21% on the surface to 0-70.92% in the subsoil and total potential/ $BaCl_2$ acidity was higher in Rubber plantations followed by oil palm, mixed plantations and paddy land use and it ranged from 1.65-23.27 meq/100 gm in surface to 1.25-26.60 meq/100 gm in the subsoil. Organic carbon content was high, but cation exchange capacity was low due to low activity clay. Thus, requires both surface and subsoil acidity amelioration. To the surface soil liming using ground limestone or calcite ($CaCO_3$), burnt lime (CaO) or dolomite ($CaCO_3.MgCO_3$), followed by tillage, was recommended. Whereas to subsoil acidity amelioration can be done by incorporation of lime and gypsum requirement @ 5-10 tonnes ha^{-1} and 10-15 tonnes ha^{-1} , respectively to surface soil was recommended as it was difficult to ameliorate directly in subsoil thereby soil acidity can be reversed and can achieve elevated yield and better income apart from maintaining soil health and quality besides controlling chemical land degradation.

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Disclaimers

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Informed consent

No animals are involved in this study or publications.

Conflict of interest

The authors declare that there are no conflicts of interest regarding the publication of this article.

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