

Original

Morphology and Characterization of an Acid Sulfate Soil from Mangrove Floodplain Area of Bangladesh.

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ABSTRACT

The studied soil was in ripe condition (field n -value < 0.6) and consisted of more than 3 horizons including sulfuric horizon within the 1.2 m of the soil surface. The soil pH was low (< 4 : field) and ECE values (0.72 – 1.62 S m^{-1}), soluble cations and anions, and exchangeable bases were relatively high throughout the profile. Water soluble SO_4^{2-} -S content was more than 1 g kg^{-1} and the total S content at ground water saturated portion (C horizon) of the soil was about 12 g kg^{-1} . The exchangeable hydrogen content (1.1 – 4.4 cmol(+) kg^{-1}) was very high, and it was attributed to the oxidation of pyritic sulfur. The high amounts of exchangeable and active Fe and Al contents of the soil can be used to categorize it as an actual acid sulfate soil.

The soil had high amounts of kaolinite and illite minerals in the clay fraction (< 0.002 mm) throughout the profile. The soil had trace amounts of smectite, chlorite, vermiculite, quartz, feldspars and interstratified 0.71 nm/ 1.01 nm and 1.01 nm/ 1.42 nm minerals. The x-ray diffraction patterns showed that jarosite was present at the deeper parts of the profile, which was attributed to the oxidation of pyrite to jarosite. The amount of 0.71 nm mineral was high in the A horizon compared to in C horizon which might be due to pedogenesis. The soil is categorized into Inceptisol order, Aquepts suborder and Sulfic Haplaquepts great group.

Key words : actual acid sulfate soil, jarosite, pedogenesis, pyrite, Sulfic Haplaquepts.

INTRODUCTION

Acid sulfate soils are characterized by a low pH and the presence of yellowish jarosite [$KFe_3(SO_4)_2(OH)_6$] mottles³⁸. Jarosite is usually found under conditions of low pH (2 – 4) and strongly oxidizing ($E_h > 400$ mV) environment⁴⁶. Acid sulfate soils were grouped into two types : actual and potential³⁰. Actual acid sulfate soils have a low pH, usually below 4.0 , and the high amount of sulfate, about 5 g kg^{-1} water soluble sulfate³⁹. Potential acid sulfate soils remain in waterlogged condition but when drained for cultivation of crops, sulfides oxidize to sulfates, resulting in extreme acidification which is harmful to crops⁴³. The term "true acid sulfate soil" was introduced and defined³⁰ as the soils have pH < 3.5 and have water soluble sulfate

of > 1 g kg^{-1} .

To be useful for management and land use planning, morphological properties and characterization of a soil are very important. These properties of acid sulfate soils include : acidity or potential acidity; salinity; chemical and mineralogical composition and texture; ripeness; profile form, especially the depth and thickness of limiting horizons; depth of water table; duration and depth of flooding etc. These properties should be quickly measured in the field and laboratory¹¹.

In Bangladesh, along the coast, about 0.23 million hectares of land are reported to be acid sulfate soils¹². These soils have never been subjected to thorough investigation from the pedological and edaphological points of view. At present, these soils are generally unproductive. If these lands can be

improved for rice cultivation, the food deficit in Bangladesh may be practically reduced. Thus, the intensive studies on distribution, genesis and classification, mineralogical and chemical properties of acid sulfate soils are needed to gain a better understanding of the soil characteristics for the consequent management and reclamation measures of acid sulfate soils of Bangladesh. In the present study, an acid sulfate soil from mangrove floodplain area of Cox's Bazar district was examined for its morphological, physico-chemical and mineralogical properties and these properties were correlated with the results of recent investigations carried out elsewhere for the similar soils.

MATERIALS AND METHODS

Study area :

Study was conducted at Cheringa acid sulfate soil of high agricultural potentiality (if they can be reclaimed by appropriate methods) which occurs in the coastal mangrove floodplain area of Cox's Bazar (Latitude 20° 26.2' N or 21° 3' N, Longitude 92° 00.0' E or 91° 6' E) in Bangladesh. The study area is popularly known as "tropical monsoon climate", or perhaps more precisely a "maritime tropical climate", has three main seasons, namely, the monsoon or rainy season, the dry or winter season and the pre-monsoon or summer season. The monsoon season extends from June to October and is warm and humid. During this period, this locality receives above 85 percent of the total annual rainfall. The dry season extends from November to February which receives very little or no rainfall and has the lowest temperature and humidity of the year. During this time drying out of the land, depletion of soil moisture and upward translocation of salts through capillary rise of subsoil moisture or ground water take place (Fig. 1). The pre-monsoon season extends from March to May and has the highest temperature and evaporation of the year. This is the period when most of the desiccation in the soil occurs accompanied by salinization and oxidation. Once this area was occupied for centuries by dense mangrove forest like sullyakata (*Dalbergia spinosa*), hargoza (*Acanthus*

ilicifolius), golpatta (*Nypa fruticans*), gewa (*Excoecaria agallocha*) and keora (*Sonneratia apetala*) etc. But now, about 90 per cent of the areas have been cleared for cultivation (local farmers have been trying to grow aman rice by fresh water irrigation where it is available) or salt production or shrimp culture. Most of the area have been subjected to tidal flooding with brackish and saline water from the tributaries of Maheshkhali and Naf rivers³⁷.

Sample and analysis of soils :

A pit of approximately 1.5m deep was dug depending on the ground water level during March, 1990. The soil profile was studied (Table 1) in accordance with the standard methods⁴⁰. The bulk samples obtained from each horizon were stored in the field-moist condition (by putting the soil samples into polyethylene bag in air-tied box) just prior to laboratory analyses whereupon sub-samples were air-dried and gently crushed to pass a 2mm sieve.

After treatment with 1M $\text{CH}_3\text{COONH}_4$ (pH 5.0) and with 30% H_2O_2 to remove free salts and organic matter, respectively, particle size distribution was determined by the pipette method¹⁰. Soil moisture at field condition was determined⁶ by over-night oven drying at 105°C. Organic matter content was determined²⁶ by wet combustion with $\text{K}_2\text{Cr}_2\text{O}_7$. Soil pH was measured in the field using Helling-Truog test-kit and for the air-dried soils in soil-water (1:1) and soil-1M KCl (1:1) suspensions¹⁹ using a Corning pH meter Model-7. The pH was also determined after H_2O_2 treatment⁴³ with slight modification of H_2O_2 concentration. For the saturation extract of soils, the electric conductivity, exchangeable sodium percentage and sodium adsorption ratio³⁶, water-soluble Na^+ and K^+ (flame photometry⁵¹), water-soluble SO_4^{2-} and Cl^- ¹⁹, and water-soluble Ca^{2+} , Mg^{2+} , Fe^{3+} , Al^{3+} , Mn^{2+} and Zn^{2+} (atomic absorption spectrometry¹⁷) were determined. Exchangeable Na^+ , K^+ , Ca^{2+} , Mg^{2+} , Mn^{2+} and Zn^{2+} were extracted with 1M $\text{CH}_3\text{COONH}_4$ (pH 7.0) and determined by flame photometry (Na^+ , K^+) and atomic absorption spectrometry. Exchangeable Al^{3+} (1M KCl⁴¹) and Fe^{3+} (1M $\text{CH}_3\text{COONH}_4$; pH 4.8⁶) were determined by atomic absorption spectrometry. The modified BaCl_2 -triethanolamine method³¹ was used for the deter-

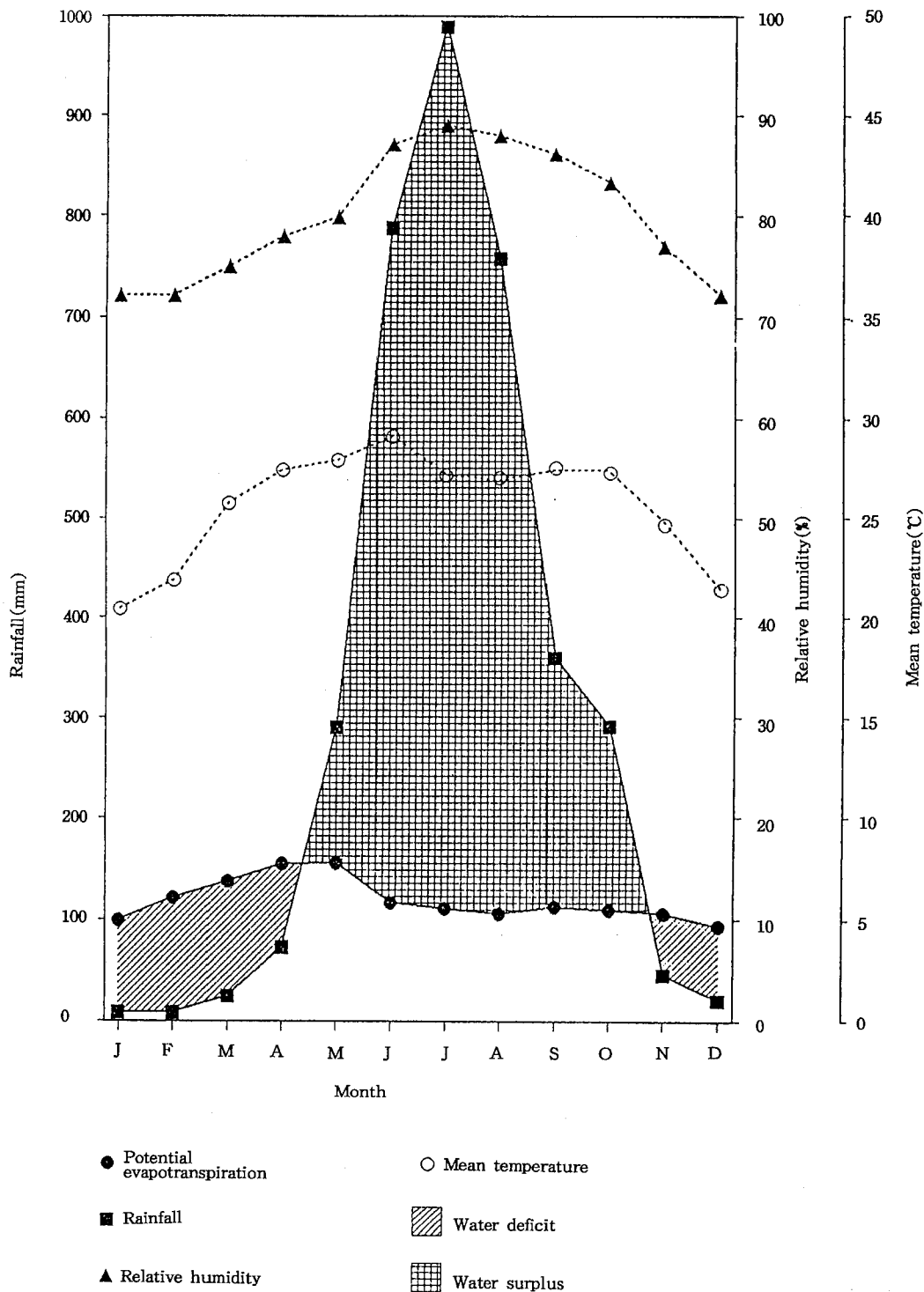


Fig. 1 Climatic data(1951-1990)and the soil water balance at the study(Cox's Bazar)area.

Table 1 Selected morphological, physical, chemical and mineralogical properties of the soil studied.

Depth(cm)	Horizon	Boundary*	Matrix color	Texture ^b	Structure ^c	Consistence ^d	Mottling color ^e	Topography	Land use	Drainage
0-10	Ap	as	5Y 5/2(moist)	SiC	massive	fi moist	cl-2Dyb and dyb	very gentle	aman/	poor, flooded
10-30	B21	as	5Y 5/1(moist)	SiC	3c-mabk/fabk	fi moist	cl-2Ddb and dyb	sloping,	fallow/	up to 55 cm
30-68	B22	aw	10YR 5/1(wet)	SiC	2c-mabk/fabk	ws and wp	cl-1Ddb and dyb	tidal flood	salt bed	for 4 to 5 months
68-122	C	—	N 5/- (wet)	SiC	massive	ws and wp	fiDdb			

Depth (cm)	Horizon	Particle-size distribution ^b (%)			Sand/Silt ratio	Moisture at field cond. (kg/kg)	Bulk density (Mg m ⁻³)	n-value at field condition	Organic matter (g kg ⁻¹)	Available		C/N ratio	Base saturation (%)
		Sand (2-0.05)	Silt (0.05-0.002)	Clay (<0.002)						N	P		
0-10	Ap	6	45	49	0.13	38	1.01	0.48	36.4	60	5.2	15.8	43
10-30	B21	9	44	47	0.21	39	1.02	0.54	23.0	43	4.3	16.2	37
30-68	B22	8	46	46	0.17	43	—	0.59	32.5	39	3.6	18.4	23
68-122	C	3	43	54	0.07	46	—	0.55	50.2	46	3.1	17.1	13

*Abbreviations of boundary : as, abrupt smooth ; aw, abrupt wavy. ^bTextural class and particle-size limit according to the international system. ^cAbbreviations of soil structure, Grade : 2, moderate ; 3, strong ; Class : c, coarse ; Type : mabk, medium angular blocky ; fabk, fine angular blocky. ^dAbbreviations of consistence : fi moist, firm moist ; ws and wp, sticky and plastic wet. ^eAbbreviations of mottling color : c, common ; 1, fine ; 2, medium ; D, distinct ; y, yellow ; b, brown ; d, dark ; f, few. n-value = (A - p × R) / (L + b × H) ; A = field moisture (%), H = organic matter (%), L = clay (%), p = 0.2 and b = 3.

(continued)

Table 1 Continued.

Depth (cm)	Horizon	CEC cmol(+)kg ⁻¹	ECe S m ⁻¹	ESP	SAR	Distribution of soil pH within the profile						
						Field cond.	Lab conditions (1:1)			Difference in pH		
						H ₂ O	KCl	H ₂ O ₂	Δ1	Δ2	Δ3	
0-10	Ap	16.7	1.62	27.13	8.82	4.5	3.2	3.1	2.7	1.3	-0.1	0.5
10-30	B21	15.1	1.16	21.39	8.32	4.1	3.1	2.7	2.6	1.0	-0.4	0.5
30-68	B22	20.2	0.90	13.61	6.02	4.0	3.2	3.0	2.6	0.8	-0.2	0.6
68-122	C	27.9	0.72	5.05	4.20	4.0	2.7	2.4	2.5	1.3	-0.3	0.2

Depth (cm)	Horizon	Exchangeable bases				Soluble ions						^b Mineralogy of clay (<0.002 mm) fractions
		Na ⁺	K ⁺	Ca ²⁺	Mg ²⁺	Na ⁺	K ⁺	Ca ²⁺	Mg ²⁺	SO ₄ ²⁻	S	
		<				>						
0-10	Ap	4.53	0.79	0.71	1.21	3.40	0.08	0.35	2.62	3.42	3.32	K, I, S, C, Q, F, Int. 1, Int. 2
10-30	B21	3.23	0.83	0.53	1.01	2.90	0.06	0.40	2.03	3.54	1.52	K, I, S, C, Q, F, Int. 1, Int. 2
30-68	B22	2.75	0.54	0.49	0.90	2.17	0.03	0.39	2.21	3.79	1.35	K, I, S, V, Q, F, J, Int. 1, Int. 2
68-122	C	1.41	0.32	0.31	1.70	1.15	0.04	0.25	1.25	2.42	1.21	K, I, S, C, Q, F, J, Int. 1

Δ1 pH = Field pH - pH(H₂O). Δ2 = pH(KCl) - pH(H₂O). Δ3 = pH(H₂O) - pH(H₂O₂). ^bOrder given represents relative abundance, K = kaolinite, I = illite, S = smectite, C = chloride, V = vermiculite, Q = quartz, F = feldspars, J = jarosite, Int. 1 = interstratified 0.71 nm/1.01 nm, Int. 2 = interstratified 1.01 nm/1.42 nm.

mination of exchangeable H⁺. Cation exchange capacity was determined by saturation with 1M CH₃COONH₄ (pH 7.0), ethanol washing, NH₄⁺ displacement with acidified 10% NaCl, and subsequent analysis by steam (Kjeldahl method) distillation⁸⁾. Available N¹⁹⁾ and P (0.5M NaHCO₃ extraction²⁰⁾)

were determined. The amount of active Fe and Mn were determined by atomic absorption spectrophotometer for the extracts of sodium hydrosulfite and EDTA solution³⁾. The amount of active Al was calculated by adding the soluble and exchangeable Al³⁺.

Total contents of Si, Al, Fe, Ti, Na, K, Ca, Mg, Mn, Zn, S and P were determined by x-ray fluorescence spectrometer (Rigaku Denki KG 4) method²⁷⁾. Soil samples were prepared as glass specimens for analyses of P, K, Ca, Mg, Fe, Mn, Si, Al, Ti and mix-pressed samples for analyses of S, Zn, Na.

Mineralogical analyses consisting of x-ray diffraction (XRD) were conducted on the <0.002 mm clay fraction. Prior to mineralogical analyses, samples were treated with 5.25% NaOCl adjusted to pH 9.5 to remove organic matter²⁸⁾. Iron oxides were removed by Na-citrate-dithionite extraction⁹⁾. Sand was separated from silt plus clay by wet-sieving, and clay was separated from silt by repeated centrifugation and decantation¹⁰⁾. Oriented mounts of the clay fraction were prepared by depositing about 250 mg on a ceramic tile³⁵⁾. For each sample, one tile was K-saturated and another Mg-saturated, both prepared by repeated leaching with 1M KCl and 0.5M MgCl₂ solutions, respectively. After running with x-ray for both the tiles at room temperature, the Mg-saturated samples were solvated with glycerol and the K-saturated samples were heated to 550°C. Again, both the K- and Mg-saturated samples were x-rayed. Identification and estimation of mineral contents were made from relative peak height or peak area by comparing with x-ray diffraction patterns of standard minerals⁴⁰⁾.

RESULTS AND DISCUSSION

Soil morphology :

The matrix color (Munsell) of top soil (Ap) of the studied profile was olive gray and subsoil color of the profile is gray (5Y 5/1 or 10YR 5/1), whereas color in substratum varies from gray to dark gray. The profile had medium distinct mottles of yellowish brown (Ap); dark brown and dark yellowish brown (B21); distinct dark brown and dark yellowish brown (B22) and dark brown (C) mottles of iron oxide (Table 1). These mottles indicate that the soil had been partly oxidized. The presence of typical yellow mottles which resemble jarosite in the B22 and C horizons of the profile suggests that the partial oxidation took place below these

jarositic horizons also. The actual acid sulfate soil profiles with jarosite have gray, bluish gray or greenish gray subsoils⁴⁷⁾ with a value higher than 4, and invariably with a chroma of 1. In the subsoil of actual acid sulfate soils with jarosite, there is a horizon having the low organic matter content as it was determined (B21 horizon) in the studied soil. Conventional Ap horizon was not found in potential acid sulfate soils⁴²⁾. The studied profile has almost similar morphological characteristics as stated above and indicated that the soil profile possesses similar properties as actual acid sulfate soils.

Physical properties :

The physical properties along with chemical and mineralogical characteristics are the most obvious criteria to recognize and classify the soils, and accordingly, these properties are studied in the field and in laboratory (Table 1). The soil had silty clay texture throughout the profile. The sand, silt and clay were distributed uniformly throughout the profile and sand/silt ratio of the soil ranged between 0.07 and 0.21 (Table 1). In Bangkok plain, textures were almost uniform in the older acid sulfate soils, where acid sulfate soils of both silty clay and very heavy clay were found⁴⁵⁾. The soil had angular blocky structure in the B horizons, and consistence of the soil was firm (Ap, B21) when moist, sticky and plastic (B22, C) when wet (Table 1).

Moisture at field condition was more or less uniformly distributed throughout the profile and ranged from 0.38 to 0.46 kg kg⁻¹ (Table 1). The bulk density was 1.01 to 1.02 Mg m⁻³ (Table 1) and within the range⁴⁵⁾ of 1 to 1.4 Mg m⁻³. The soil had n-values ranging from 0.48 to 0.59 under field condition (Table 1), indicating that the soil was in ripe condition. Sometimes, the n-value is used as a criterion for separation of Inceptisols from Entisols. The soils in order Entisols should have an n-value of 0.7 or more in one or more sub-horizon between 20 to 50 cm below the mineral soil surface. On the other hand, Inceptisols have n-value of <0.7 to a depth of at least 50 cm. Moreover, the soil contained yellow mottles of jarosite in some parts between 30 to 122 cm depth

that was formed under temperate climate and had a pH < 4.0 (1 : 1 water), and contained more than 1 g kg⁻¹ soluble SO₄²⁻S indicated that the sulfuric horizon was present within the 1.2 m of the soil surface. Thus, the studied soil can be placed into the Inceptisol order, Aquept suborder and Sulfic Haplaquept great group on the basis of Soil Taxonomy system^{18,21}.

Chemical properties

Soil reaction (pH) : At field condition, the pH of the surface soil was slightly higher than the pH of the subsoils, which may be due to occasional flooding with brackish and saline water. The differences in pH between the field and laboratory conditions ranged from 0.8 to 1.3. These differences in pH indicated that the soil probably accumulated high amount of pyrite which has produced some H₂SO₄ in the laboratory by oxidation. The pH of soil treated with 3% H₂O₂ (1 : 1) was found to be lower than the pH for the water and KCl suspensions in all the horizons, except for the C horizon (Table 1). The reason for decrease of pH by the H₂O₂ treatment may be due to the production of H₂SO₄ by oxidation of pyrite. The difference in pH between 1 : 1 soil-water and 1 : 1 soil-H₂O₂ suspensions was less than 0.6 pH unit which may be used as a criterion to classify the soils as an actual acid sulfate soil. Significant correlations were found between the pH of field moist samples and ECe ($r=0.61^{**}$), active Fe ($r=-0.90^{**}$) and Al ($r=-0.87^{**}$), and soluble Fe³⁺ ($r=-0.62^{**}$) and Al³⁺ ($r=-0.94^{**}$).

Measurement of pH on acid sulfate soils in Malaysia²⁾ and in New Zealand²⁴⁾, suggests that a pH value of 4.0 in the field or of a dried sample in 0.01M CaCl₂ or 1M KCl was low enough to cause acid sulfate problems. The studied soil (air-dried) had pH around 3.0 in all the horizons. The pH values of the air-dried soils fell below the standard categories of pH values used to separate it from ordinary acidic mineral soils. For ordinary acidic mineral soils, the usual pH level was described as extremely acidic when the pH range is between 4.0 and 4.5³⁹⁾. The pH level of the studied soil categorized it into actual acid sulfate soil. In addition to acute drop of the pH value upon drying and

the typical yellow mottles which resemble jarosite were observed below the surface horizons of the soil. Thus, it could be said that the soil contains appreciable amount of pyrite which is the source of acidity development in the soil.

Electric conductivity (ECe) : The soil had high ECe values ranging from 0.72 to 1.62 S m⁻¹ (Table 1). Salinity levels in acid sulfate soils are variable. The highest level occurs in young acid sulfate soils in regions with a prolonged dry season such as Senegambia, where ECe values in excess of 8.0 S m⁻¹ occur in the upper 30 cm and surface salt crust is formed during the dry season²⁹⁾. The ESP and SAR of the soil ranged from 5 to 27 and 4 to 9, respectively throughout the profile (Table 1). These values were high at the surface soils and gradually decreased with the deeper depths of the soil profile. The ESP of the surface horizons was more than 20 but did not show any apparent effect of sodicity or dispersion of the soil particles within the profile.

Organic matter : The soil had high organic matter content (23–50 g kg⁻¹) but the lowest in B21 horizon (Table 1). Similar levels of organic matter have been reported⁵⁾ in the acid sulfate soils of Thailand. Based on the classification²⁰⁾ of soils on the basis of organic matter content and CEC, the soil fell into the medium high range (34–55 g kg⁻¹) of organic matter content. Organic matter content was found to show significant correlation with CEC ($r=0.85^{**}$) and exchangeable Ca²⁺ (0.56^{**}) and Mg²⁺ (0.84^{**}). It had also significant correlation with exchangeable H⁺ ($r=0.72^{**}$), Al³⁺ (0.84^{**}) and Fe³⁺ (0.79^{**}) indicating that the organic matter was directly related to the formation of acids. The carbon-nitrogen ratio was variable in the profile and ranged from 15.8 to 18.4 (Table 1).

Available Nitrogen and Phosphorus : The amount of available nitrogen (39–60 mg kg⁻¹) and phosphorus (3–5 mg kg⁻¹) contents of the soil were very low throughout the profile, which may be due to the minimum activity of organic matter transforming bacteria in both acidic and reduced non-acidic saline or brackish pyritic conditions.

CEC and exchangeable bases : The CEC of the soil

ranged between 15.1 to 27.9 $\text{cmol}(+)\text{kg}^{-1}$ (Table 1) and the results were agreed well with the values obtained elsewhere for similar soils. The Kattampally swamp soils of Kerala, India²⁵⁾ had the CEC values ranging between 13 and 26 $\text{cmol}(+)\text{kg}^{-1}$. A significant positive correlation was obtained between CEC and amounts of organic matter ($r=0.85^{**}$) and clay contents ($r=0.82^{**}$) indicated that the variation in CEC of the soil was related with the variation in organic matter and clay content of the soil. The exchangeable Na^+ , K^+ , and Ca^{2+} decreased at the lower depth (Table 1). The exchangeable Mg^{2+} concentration of the soil was very high in relation to Ca^{2+} , which is indicative of old marine deposits in which the Ca is largely leached but Mg is maintained at a relatively high level, probably as a result of a progressive clay disintegration and release of $\text{Mg}^{11)}$. The percentage of base saturation ranged from 13 to 43 and decreased with increased depth. The percentage of base saturation had a positive correlation ($r=0.74^{**}$) with the pH and similar results were reported²⁶⁾.

Exchangeable H^+ , Al^{3+} and Fe^{3+} : The exchangeable H^+ is one of the important characteristics of acid sulfate soils. The exchangeable H^+ of the studied soil ranged from 1.07 to 4.37 $\text{cmol}(+)\text{kg}^{-1}$ throughout the profile (Table 2). The content of exchangeable H^+ was found to be higher at the lower depth of the soil. The highest amount of exchangeable H^+ in the C horizon can be attributed to the oxidation of pyritic sulfur when the soil was dried for the laboratory analyses. The exchangeable Al^{3+} ranged from 9.22 to 17.52 $\text{cmol}(+)\text{kg}^{-1}$ throughout the profile, and increased with the decrease of soil pH. At low pH, more aluminum comes into solution and as a result, more adsorption takes place. It was noticed^{4,15)} that the exchangeable Al^{3+} of mangrove soils rose steeply as soon as the pH fell below 4.0. The exchangeable Fe^{3+} varied from 3.43 to 8.58 $\text{cmol}(+)\text{kg}^{-1}$ in the profile and increased at the lower depth as in the case of exchangeable Al^{3+} . Increment of water soluble and exchangeable iron was favored by decrease in redox potential and $\text{pH}^{10)}$.

Water soluble ions : The soluble Al^{3+} ranged from 0.99 to 2.35 $\text{cmol}(+)\text{kg}^{-1}$ throughout the profile (Table

2) and showed a significant negative relationship ($r=-0.94^{**}$) with the soil pH. The soluble Al^{3+} in acid sulfate soils of North-West Malaysia²⁾ ranged from 0 to 8.5 $\text{cmol}(+)\text{kg}^{-1}$ with the pH range of 4.2 to 3.2. Aluminum activity was inversely related to pH, increasing roughly 10 fold per unit pH decrease^{44,45)}. Soluble Fe^{3+} ranged from 0.25 to 0.27 $\text{cmol}(+)\text{kg}^{-1}$ in the soil. Soluble iron concentration is not normally high and some soils have very little soluble iron³²⁾. The distribution of soluble Fe^{3+} within the profile was more or less uniform. Soluble Mn^{2+} ranged between 0.22 and 0.36 $\text{cmol}(+)\text{kg}^{-1}$ in the soil. The lower horizons of the soil profile had the higher amount of soluble Mn^{2+} . The soil had very low quantity of soluble Zn^{2+} ranged from 0.03 to 0.09 $\text{cmol}(+)\text{kg}^{-1}$ and the quantity of zinc was a little high at the lower horizons than the upper horizons of the profile. The soluble Cl^- ranged from 1.21 to 3.32 $\text{cmol}(-)\text{kg}^{-1}$ and showed the highest accumulation at the surface horizon (Table 1). The amount of soluble SO_4^{2-} -S ranged between 2.42 and 3.79 $\text{cmol}(-)\text{kg}^{-1}$ in the soil profile and the similar quantities S was also determined⁷⁾.

Active Al, Fe and Mn : The active Al content was high and ranged between 10.45 and 19.87 $\text{cmol}(+)\text{kg}^{-1}$ within the profile (Table 2). The active Al increase with decrease of $\text{pH}^{44)}$. This is true to the present acid sulfate soil ($r=-0.87^{**}$). It was also reported that the Ransit acid sulfate soils (pH 3.9) of Thailand had the higher amount of active Al than other soils possessing relatively high pH values⁴⁾. The active Fe was high and ranged from 23.95 to 34.60 $\text{cmol}(+)\text{kg}^{-1}$ throughout the profile. Active Fe had a significant correlation with pH ($r=-0.90^{**}$). The soil contained a small amount of active Mn, which ranged from 0.04 to 0.13 $\text{cmol}(+)\text{kg}^{-1}$ throughout the profile (Table 2). The active Mn of acid sulfate soils of Thailand, Vietnam and Philippines³²⁾ ranged from 0.02 to 1.46 $\text{cmol}(+)\text{kg}^{-1}$.

Total content of some elements : The distribution of total Si, Al, Fe and Ti contents were more or less uniform throughout the profile (Table 2). Uniformity of SiO_2 content within the soil profile indicate the uniformity in chemical composition of

Table 2 Quantities in different forms of some selected elements relating to acidity of the soil studied.

Depth (cm)	Horizon	Soluble				Exchangeable			Active		
		Al ³⁺	Fe ³⁺	Mn ²⁺	Zn ²⁺	H ⁺	Al ³⁺	Fe ³⁺	Al	Fe	Mn
← cmol(+)kg ⁻¹ →											
0-10	Ap	1.14	0.25	0.29	0.06	1.07	9.83	3.43	10.97	25.14	0.04
10-30	B21	1.23	0.27	0.22	0.03	1.23	9.22	3.60	10.45	23.95	0.04
30-68	B22	0.99	0.26	0.29	0.09	2.98	11.97	5.55	12.96	25.04	0.07
68-122	C	2.35	0.27	0.36	0.09	4.37	17.52	8.58	19.87	34.60	0.13

Depth (cm)	Horizon	Total quantities of some elements											Si/Al ratio	Si/R* ratio	
		Si	Al	Fe	Ti	Na	K	Ca	Mg	Zn	Mn	S			P
← g kg ⁻¹ →														← mg kg ⁻¹ →	
0-10	Ap	275	66.7	54.5	4.0	7.6	24.3	1.5	5.6	52	290	3097	695	4.12	2.27
10-30	B21	287	73.5	39.1	4.3	7.4	25.9	1.6	7.2	25	140	2970	687	3.90	2.55
30-68	B22	294	71.1	31.5	4.1	8.6	27.0	1.7	6.0	52	290	7080	562	4.14	2.87
68-122	C	268	67.0	43.4	4.0	6.8	23.9	1.6	7.7	32	180	1000	538	3.99	2.54

*R=Al+Fe

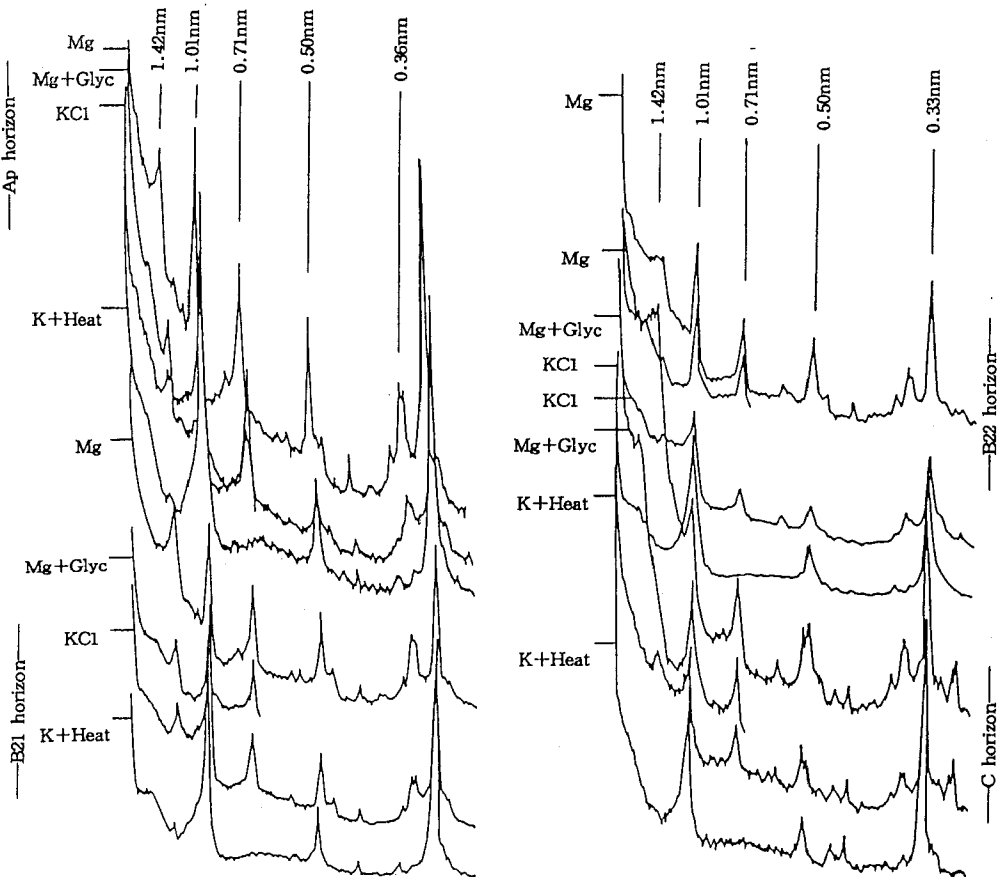


Fig. 2 X-ray diffractograms of clay fraction of Cheringa acid sulfate soil.

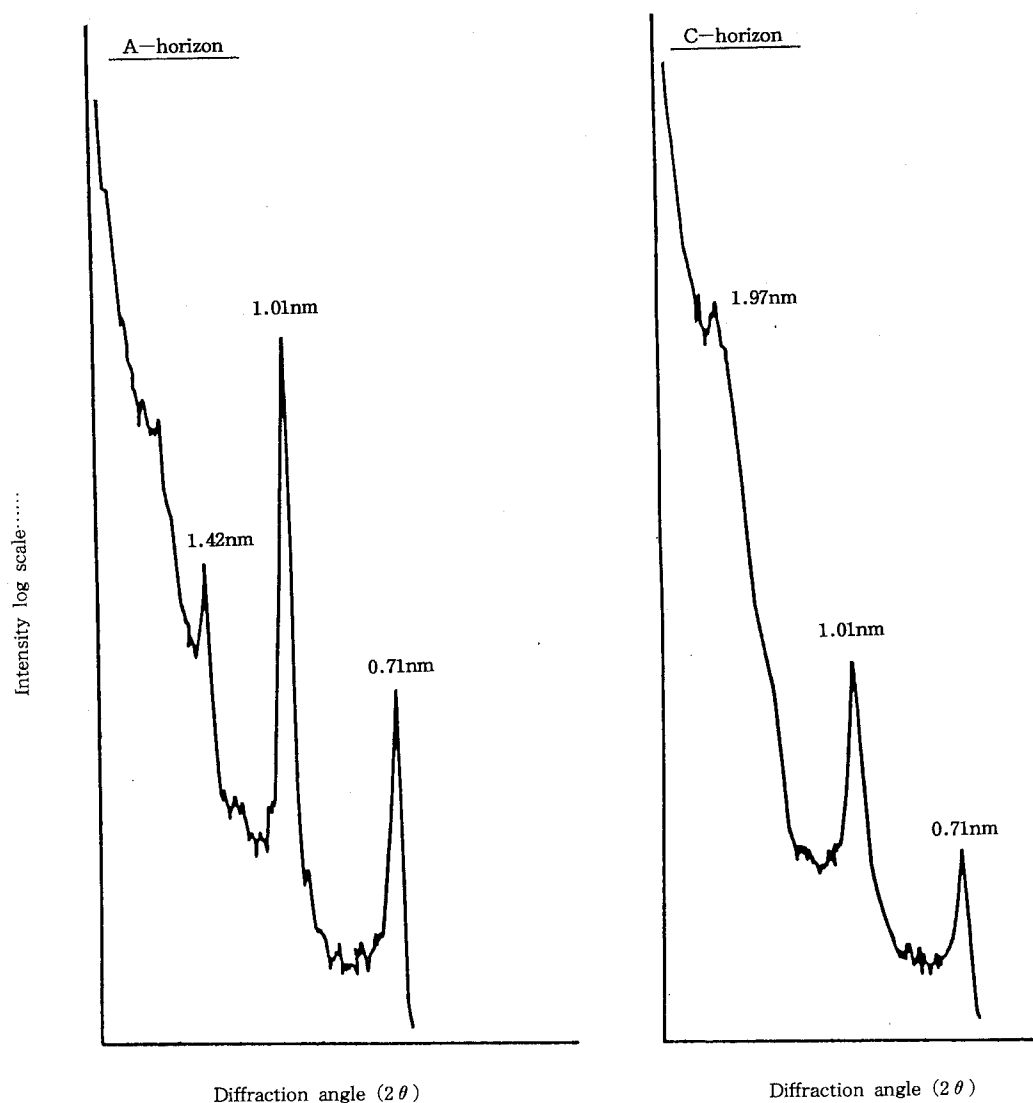


Fig. 3 X-ray diffractograms of Mg-saturated glycolated clay samples from A and C — horizons of Cheringa acid sulfate soil.

parent material of the soil. Total content of K ($24-27 \text{ g kg}^{-1}$) throughout the profile was the highest among Na ($6.8-8.6$), Ca ($1.5-1.7$) and Mg ($5.6-7.7 \text{ g kg}^{-1}$) which might be due to the higher amount of K bearing minerals in the soil. The total amount of Mg was higher than the total amount of Ca indicated that the soil materials are of marine deposits, moreover, the higher content of Mg in the sea and the ground water of Cox's

Bazar coastal plain has dominant Mg cation next to Na^{27} . The total content of Zn ranged from 25 to 52 mg kg^{-1} within the profile. The variation in total Mg, Ca and Zn were related to stage of development of soil, the well developed acid sulfate soils contained lower amounts of these elements. Total S content varied from 3 to 12 g kg^{-1} throughout the profile. The total S at ground water saturated portion (C horizon) was about 12 g kg^{-1} and this

amount is within the range of acid sulfate soils as identified⁴⁰⁾. The content of P ranged between 0.5 to 0.7 g kg⁻¹. These values are within the range (0.6–0.8 g kg⁻¹) obtained in acid sulfate soils of Kerala, India¹³⁾. As expected, the total content of P was higher in less developed potential acid sulfate soils than in well developed actual acid sulfate soils.

Clay mineralogical properties :

The x-ray diffractograms of the clay fraction (< 0.002 mm) from all horizons are presented in Figure 2. The relative amounts of 0.71, 1.01 and 1.42 nm clay minerals were determined semi-quantitatively based on peak heights or peak areas of the x-ray diffraction patterns. The high amounts of kaolinite and illite clay minerals were identified throughout the profile (Table 1). The trace amounts of smectite, chlorite, vermiculite, quartz, feldspars and interstratified 0.71 nm/1.01 nm and 1.01 nm/1.42 nm minerals were also detected. The x-ray diffraction patterns indicated that the jarosite minerals was present only at the clay fractions of the B22 and C horizons, which was attributed to strong oxidation of pyrite converting to jarosite. The x-ray diffractograms of the Mg-saturated and glycol-solvated clay samples of the A and C horizons were used to see the effect of pedogenic processes on the mineralogical composition in the profile (Fig.3). Figure 3 shows that the amount of 0.71 nm minerals is high in the A horizon than in the C horizon, which is an indication of pedogenesis. In this profile, the amount of 1.01 and 1.42 nm minerals were also quite high in the A horizon than in the C horizon. Kaolinite and smectites were the dominant minerals of clay fractions in some acid sulfate soils of Kerala, India¹³⁾. The reason for the high amount of mica in the studied acid sulfate soil of Cox's Bazar in Bangladesh may be due to the nature of their parent materials. In some soils from Gangetic alluvial plain at the coastal belt of Bangladesh, high amounts of mica, Kaolinite and smectites in the clay fraction were identified¹⁶⁾. The present studied acid sulfate soil from Cox's Bazar area was formed on alluvial other than Gangetic. As a result, the amount of smectites in them is quite small³⁷⁾.

SUMMARY

The studied soil was in ripe condition and is characterized as Inceptisol order, Aquepts suborder and Sulfic Haplaquepts great group^{18,21)}. The soil contained yellow mottles which resemble jarosite in the B22 and C horizons. The ECe, Soluble Na⁺, Mg²⁺, Al³⁺, Cl⁻ and SO₄²⁻-S and exchangeable Na⁺, Mg²⁺, H⁺ and Al³⁺ were relatively high. The pH, presence of sulfuric and Ap horizons, >1 g kg⁻¹ water soluble SO₄²⁻-S, and high amounts of exchangeable and active Fe and Al in the soil can categorize it into an actual³⁴⁾ or true³⁰⁾ acid sulfate soil.

The soil had high amounts of kaolinite and illite clay minerals in the clay fractions throughout the profile. The soil also had trace amounts of smectite, chlorite, vermiculite, quartz, feldspars and interstratified 0.71 nm/1.01 nm and 1.01 nm/1.42 nm minerals.

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