Indonesian Journal of Agricultural Science 2(1),2001: 10-26

CHARACTERISTICS OF RICE SOILS FROM THE TIDAL FLAT AREAS OF MUSI BANYUASIN, SOUTH SUMATRA

B.H. Prasetyo, S. Suping, Subagyo H., Mujiono, and H. Suhardjo

Center for Soil and Agroclimate Research and Development, Jalan Ir. H. Juanda 98, Bogor 16123, Indonesia

ABSTRACT

Tidal flats in the Musi Banyuasin region that cover more than 200,000 ha are the largest area for agricultural development in South Sumatra Province. Only about a half of this has been used for tidal swamp rice fields, therefore, the other half needs to be developed. To obtain a better understanding of their properties for appropriate soil management, soil characteristics of the area need to be studied. To characterize the soil, thirty-four soil samples from seven soil profiles were analyzed for their chemical and mineralogical composition at the laboratories of the Center for Soil and Agroclimate Research and Development. The results indicate that soils from the tidal flat areas have an aquic soil moisture regime, the upper parts of the soils are mostly ripe, and most of the pedons show the presence of sulfidic materials below 65 cm of the mineral soil surface. The soils are classified as Sulfic Endoaquept (P1, P2), Histic Sulfaquent (P3), Typic Sulfaquept (P4), Fluvaquentic Endoaquept (P5), and Sulfic Hydraquent (P6, P7). Mineral composition of the sand fraction is dominated by quartz, while the clay minerals consist of predominantly kaolinite, mixed with small amount of smectite, illite, quartz, and crystoballite. Organic carbon content is high to very high, potential phosphate content of most pedons ranges from very low to medium, while potential potassium content varies from very low to medium in the upper layers and medium to very high in the bottom layers. Phosphate retention of topsoil sample varies from 56 to 97%, and is positively correlated (r^2 = 0.73) with aluminum from amorphous materials. Exchangeable cations are dominated by Mg cation, and in all pedons cation exchange capacity values are medium to very high, and seem to be influenced by organic carbon. Specific chemical properties, particularly soil pH and content of exchangeable aluminum exhibit a significant change about 1-2 months after soil samples were taken from the field. Theoretically, interaction between good water management and fertilizer application are among the choices of management to make these soils productive.

[*Keywords*: rice fields; acid soils; tides; soil chemicophysical properties; South Sumatra]

INTRODUCTION

Rice field development in tidal flat areas is one of the important solutions to raising national rice production. Tidal flats are extensive, flat to nearly horizontal marshy land near the sea, that is alternately flooded and unflooded by daily tides, and consists of unconsolidated fine sediment (mostly mud). Tidal flat soils are soils derived from fine marine sediment that contains sulfidic materials, popularly called “pyrite”. Even though sulfidic containing soils are problem soils, these soils have a favourable topography and hydrology that appear to make them suitable for agriculture, especially lowland rice field. Indeed during the first long term development program (1970-1993), the government through Department of Public Work successfully implemented the Tidal Swamp Rice Development Project. During that period, a total area of about 1.4 million ha was reclaimed for the whole of Indonesia. In Sumatra, a total area of 686,583 ha was reclaimed for agricultural uses, and out of this about 301,870 ha is located in South Sumatra Province (Departemen Pekerjaan Umum, 1998).

Other data indicate that the total reclaimed tidal flat areas in South Sumatra is about 329,897 ha, and almost entirely within the administrative district of Musi Banyuasin. Musi Banyuasin is then the largest reclamation area in South Sumatra. Reclamation of the tidal flat areas took place between 1969-1990 and the area is used for a transmigration settlement. For transmigrantion settlement, the area is divided into 16 units or locations, each about 2,000-50,000 ha. Eleven of these 16 units are developed for tidal flat rice fields, commonly called tidal swamp rice fields. In 1998, total area that had been reclaimed for agriculture was about 233,598 ha, and 137,228 ha (58%) of it was used for tidal swamp rice fields (Badan Penelitian dan Pengembangan Pertanian, 1998).

Soils of the tidal flat areas in Musi Banyuasin are developed from marine sediment. This type of soil is characterized by the presence of sulfidic materials, which upon oxidation after exposure to air by land reclamation, and if conditions are suitable may result in a soil that is extremely acid (pH < 3.5). Since the acidity comes from the production of sulphuric acid, the extremely acid soils are called “acid sulphate soils”. The presence of sulfidic materials signifies that the soils may or may not possibly be developed into an acid sulphate soil, depending upon oxidation conditions and the presence of neutralizing compounds. Therefore, these marine sulfidic containing soils are often called “potential acid sulphate soils”. Successful reclamation of tidal flat areas may result in the development of productive rice field. While poor soil reclamation may lead to creation of unfavourable soil conditions for crop growth and formation of acid sulphate soils, the real problem in the tidal flat areas.

Since its development for settlement and rice production area in the 1970s, only a very few studies on soils have been conducted. All are in the form of soil survey or soil characterization, for instance the detailed soil survey of Karang Agung Tengah, scale 1:10,000, to support development of tidal swamp rice farming systems (Puslittanak, 1989), the soil characterization to support Tidal Swamp Agricultural Development Project South Sumatra, Phase I (Badan Penelitian dan Pengembangan Pertanian, 1998), and Phase II (Badan Penelitian dan Pengembangan Pertanian, 1999). Some of the results have been reported by Suryanto *et al*. (1991) and Syukur *et al.* (2000). However, almost none discussed soil characteristics and pedogenesis.

This paper aims to discuss soil morphology, mineralogical composition, and chemical properties of some rice soils of the tidal flat areas in Musi Banyuasin, South Sumatra

MATERIALS AND METHODS

The study was conducted at Musi Banyuasin, South Sumatra, and covered seven locations, i.e., Delta Upang, Delta Saleh, Sugihan Kiri, Sugihan Kanan, Delta Telang I, Delta Telang II, and Karang Agung Ulu (Fig. 1). These locations were chosen since they represent the major tidal flat rice field areas, which presently have become one of the few rice production centers in South Sumatra. At present, the area is less prosperous compared to relatively prosperous transmigration settlements surrounded by vast area of tidal swamp rice fields. The average annual rainfall in the study area is between 2,460 and 2,454 mm. The wet season generally occurs from December to April, which according to Oldeman *et al.* (1979) is grouped as C1 agroclimatic zone, and according to Schmidt and Ferguson (1951) as having an A rainfall type.

The soil study was carried out through observation of soil profiles, by digging “mini” pits, of approximately 50 cm deep, and then continued by a soil auger to a depth of about 150 cm. Soils were classified following Soil Taxonomy (Soil Survey Staff, 1999). In the field, the presence of sulfidic materials was checked by reaction with hydrogen peroxide (H_2O_2 10%). A strong effervescence with sulfur odor and a severe drop of soil-pH value to about pH < 3.0, indicated the presence of sulfidic materials.

During the field study, seven pedons, i.e., P1 (Delta Upang), P2 (Delta Saleh), P3 (Sugihan Kiri), P4 (Sugihan Kanan), P5 (Delta Telang I), P6 (Delta Telang II), and P7 (Karang Agung Ulu) were observed, and 34 horizon soil samples were taken for laboratory analyses. The pedons were chosen based on their relative distance from the sea, from pedon P1 that is the nearest, up to pedon P7 that is the farthest. In addition, soil samples from topsoils were also taken from randomly selected pedons (P1, P4, and P5). In each selected pedon, there were eight topsoil samples collected around the pit, so 24 topsoil samples were taken. The data from the topsoils are used only to find out the relationships between some important soil properties and chemical characteristics.

In the laboratory, the horizon soil samples were analysed for their physico-chemical properties and mineralogical composition. The physico-chemical analyses included particle size analysis, organic carbon, pH (H_2O and KCl), exchangeable cations and cation exchange capacity (CEC) by 1 N NH_4OAc, pH 7 extraction, exchangeable acidity (by 1 N KCl), available phosphate (P), potential P and K (by 25% 1N HCl), water-soluble sulphate, and total sulphur content. Topsoil samples were analysed only for selected chemical properties, i.e., pH (H_2O), P retention, Al and Fe contents by acid ammonium oxalate extraction. With the exception of P-retention by the method of Blackmore *et al.* (1981), and available P by the Bray-I method, all other soil analyses were conducted following the methods described in Soil Survey Laboratory Staff (1991). Mineralogical analyses were conducted on sand and clay fractions. Sand fractions were analysed by polarizing microscope, while the clay fractions were analysed by X-ray diffractometer (XRD). Prior to the XRD run, the clay sample was treated with the standard procedure, that is saturating the samples with Mg, Mg plus glycerol, K, and K plus heating at 550^{o}C. Considering that most pedons have the same parent material, the mineralogy analyses of sand fractions were only done for pedons P1, P4, and P5.

Fig. 1. Map of Musi Banyuasin area, South Sumatra, showing the location of the pedons studied.

RESULTS AND DISCUSSION

Soil Morphology and Classification

All pedons show gley color in their matrix and exhibit a positive reaction with α-α *dypiridil*, indicating that the soils have an aquic soil moisture regime. This is also confirmed by the presence of gleyed-horizons in all pedons, mostly started within 50 cm from the soil surface (Table 1). Soil texture varies from clay, silty clay to silty clay loam. The upper parts of the soils are mostly ripe (R) to nearly ripe (NR), while the subsoils vary between half-ripe (HR) and unripe (UR).

Since soils are generally poorly drained with aquic conditions, organic carbon content of the surface plow layer generally remains high. Some pedons even show a peaty layer on the surface, such as in pedons P1 (Delta Upang), P2 (Delta Saleh), and P4 (Sugihan Kanan). Some other pedons, such as pedon P3 (Sugihan Kiri), are found to have a sapric organic layer of about 40 cm. This area was formerly a vast area of deep peat, but after 22-25 years of reclamation and the land being used for rice fields and upland farming, in many places the peat has drastically decreased to a thickness of less than 50 cm.

The presence of sulfidic materials was proven by strong effervescence and sulphur odor, upon reaction of H_2O_2 with the soil mass. With the exception of pedon P5 (Delta Telang I) that did not show the presence of sulfidic materials to a depth of 150 cm, and pedon P1 (Delta Upang) that has sulfidic materials within 50 cm of the soil surface, all the rest of the pedons show the presence of sulfidic materials below 65 cm of the mineral soil surface.

Diagnostic soil properties vary among the pedons. Soil horizons at the depth between 20 and 50 cm of pedons P1, P2, P4, and P5 are ripe. The soils also have a cambic horizon, thus the soils can be classified as Inceptisols. Among these four pedons only pedon P4 (Sugihan Kanan) shows the presence of a sulfuric horizon between 31 and 73 cm, which is indicated by its field soil pH of less than 3.5, and the presence of jarosite mottles with a color of 2.5 Y 5/6. Sulfidic materials, as shown by its content of water-soluble

Table 1. Morphological characteristics and diagnostic properties of rice soils of the tidal flat area of Musi Banyuasin, South Sumatra.

Depth (cm)	Horizon	Color Matrix	Color Mottles	Soil ripeness	H_2O_2 reaction	Field-pH (H_2O_2) Before	Field-pH (H_2O_2) After	Texture	Diagnostic properties
Pedon P1 (Delta Upang)									
0-9/15	Oa	10YR3/2	2.5YR4/6	R	-	5.0	-	Sapric	Ochric
9/15-36	Bg	2.5Y5/2	5YR4/3	R	-	5.0	-	C	Cambic
36-65	BCg	2.5Y5/2	-	R	-	5.0	-	C	Sulfidic materials
65-116	Cg	N4/0	-	HR	Strong	6.0	2	C	
116-150	2Cg1	5GY6/1	-	UR	Strong	6.0	2	SiC	
Pedon P2 (Delta Saleh)									
0-26	Ap	5YR3/2	-	-	-	4.5	-	SiC	Ochric
26-48	Bg	2.5Y5/2	-	R	-	5.0	-	SiC	Cambic
48-65	Cg	N4/0	-	HR	-	5.0	-	C	
65-98	2Cg1	5B5/1	-	HR	Strong	6.5	2	C	Sulfidic materials
98-140	2Cg2	5B6/1	-	HR	Strong	6.5	2	C	
Pedon P3 (Sugihan Kiri)									
0-15	Oa1	5YR3/2	-	-	-	5.5	-	sapric	Histic
15-40	Oa2	5YR3/3	-	-	-	4.5	-	sapric	
40-65	Cg1	10YR6/2	2.5YR3/4	HR	-	5.5	-	SiC	
65-110	Cg2	N4/0	-	HR	Strong	7.0	2	C	Sulfidic materials
110-150	Cg3	5Y5/1	-	UR	Strong	8.0	2	C	
Pedon P4 (Sugihan Kanan)									
0-12	Ap	5YR3/3	-	-	-	4.5	-	SiC	Ochric
12-31	Bg1	10YR6/2	7.5YR3/4	R	-	4.0	-	C	Cambic
31-73	Bg2	5Y6/1	2.5Y5/6	R	-	3.0	-	C	Sulfuric horizon
73-95	Cg1	5Y5/1	-	HR	Strong	6.5	2	SiC	Sulfidic materials
95-130	2Cg2	N5/0	-	UR	Strong	7.0	2	SiC	
Pedon P5 (Delta Telang I)									
0-19	Ap	10YR4/1	-	R	-	5.5	-	SiC	Ochric
19-46	Bg1	10YR6/2	5YR4/6	R	-	5.0	-	C	Cambic
46-72	Bg2	2.5Y5/2	5YR3/4	R	-	5.0	-	C	
72-110	BCg	2.5Y5/2	7.5YR4/4	NR	-	5.0	-	SiC	
110-150	2Cg	N4/0	-	HR	Strong	7.0	2	SiC	
Pedon P6 (Delta Telang II)									
0-16	Ap	10YR5/2	-	NR	-	5.0	-	SiCL	Ochric
16-45	Cg1	2.5Y5/2	-	HR	-	4.5	-	SiCL	
45-66	Cg2	2.5Y5/2	-	UR	-	4.5	-	SiCL	
66-108	Cg3	N5/0	-	UR	Strong	7.0	2	SiCL	Sulfidic materials
108-140	Cg4	5GY5/1	-	UR	Strong	7.0	2	SiCL	
Pedon P7 (Karang Agung Ulu)									
0-16	Ap	2.5Y5/2	5YR4/4	NR	-	4.5	-	C	Ochric
16-40	Cg	2.5Y5/2	-	HR	-	5.0	-	C	
40-90	2Cg1	N5/0	-	UR	Strong	6.5	2	C	
90-13	2Cg2	5Y5/1	-	UR	Strong	6.5	2	C	Sulfidic materials

R = ripe, NR = nearly ripe, HR = half-ripe, UR = unripe ; C= clay, SiC = silty clay, SiCL= silty clay loam; sulfidic materials = the layer in which sulfidic materials start to present.

sulphate 0.05% or more, are found starting at a depth of 36 cm (pedon P1), 65 cm (pedon P2), 73 cm (pedon P4), and below 150 cm (pedon P5), respectively.

According to van Breemen (1976), jarosite in a sulfuric horizon is formed at pH between 2 and 4, with an Eh value greater than 410 mV. This finding was quite different from the results reported by Janssen *et al.* (1990), obtained from the acid sulphate soils in Pulau Petak area, South Kalimantan. In Pulau Petak area, many jarosite mottles present in acid sulphate soils, and the horizon in which the jarosite mottles present, were in the horizons with the most active pyrite oxidation.

Soil horizon of pedons P3, P6, and P7, below the histic epipedon (pedon P3), and at a depth between 16 and 40 cm are half-ripe. Sulfidic materials, as shown by the content of water-soluble sulphate of 0.05% or more, are present starting from a depth of 65 cm (pedon P3), 66 cm (pedon P6), and 90 cm (pedon P7), respectively. The soils do not sufficiently fulfil the requirement of a cambic horizon, therefore they are classified as Entisols.

The result of soil classification up to soil family level following Soil Taxonomy procedure (Soil Survey Staff, 1999) is given in Table 2. Pedons P1 and P2 that are more ripe have a cambic horizon, but have not developed a sulfuric horizon, and show the presence of sulfidic materials within 150 cm of the mineral soil surface, are classified as Sulfic Endoaquept. They have fine or very fine particle size class, either kaolinitic or mixed mineralogy, and are nonacid. Pedon P5 has similar development, but sulfidic materials are not found within 150 cm of the mineral soil surface, so it is classified as Fluvaquentic Endoaquept. Pedon P4 (Sugihan Kanan) is the only one that is ripe and has developed a sulfuric horizon, and therefore is appropriate as an acid sulphate soil. In Soil Taxonomy, it is classified as a Typic Sulfaquept, with very fine particle size class and mixed mineralogy, and it is acid.

The surface horizons of pedons P3, P6, and P7 either have a thin layer of peat or are nearly ripe, while the subsurface horizons are unripe, starting respectively at 110 cm in pedon P3 and around 40 cm in pedons P6 and P7. Since sulfidic materials are present within 50 cm of the mineral soil surface, and it has a histic epipedon, pedon P3 is classified as Histic Sulfaquent. Pedons P6 and P7 are already unripe within 50 cm of the mineral soil surface, and since sulfidic materials are present within 100 cm of the mineral soil surface, they are classified as Sulfic Hydraquent. The three pedons have similar characteristics, that is, they have fine to very fine particle size class and kaolinitic clay mineralogy, and are also nonacid. Pedon P3 actually could be classified as Histosols, but with consideration that the peat layers in rice fields of the tidal flat areas have become thinner, this soil is more appropriate to be classified as Entisols.

The results of classification tend to show that distance from the sea seems not to have an influence on rice soil development. As soils are basically developed from similar sediment containing sulfidic materials, after about 30-40-year reclamation, similar tidal flat rice soils may in fact at present still have shallow (less than 50 cm) sulfidic materials with or without formation of sulfuric horizon, or have medium depth (50-100 cm) sulfidic materials, and even may not have anymore sulfidic materials to a depth of 150 cm below the mineral soil surface. Of the many factors governing this, the most likely is water management in the tidal flat rice fields. Proper water management supported by well maintained primary, secondary, and tertiary canals, enhances the rapid removal of toxic compounds produced from of sulfidic material oxidation in the soil environment.

Table 2. Soil classification of rice soils of the tidal flats of Musi Banyuasin, South Sumatra.

Pedon		Soil classification (Soil Survey Staff, 1999)
P1	Delta Upang	Sulfic Endoaquept, very fine, mixed, active, nonacid, isohyperthermic
P2	Delta Saleh	Sulfic Endoaquept, fine, kaolinitic, nonacid, isohyperthermic
P3	Sugihan Kiri	Histic Sulfaquent, fine, kaolinitic, nonacid, isohyperthermic
P4	Sugihan Kanan	Typic Sulfaquept, very fine, mixed, semiactive, acid, isohyperthermic
P5	Delta Telang I	Fluvaquentic Endoaquept, very fine, mixed, semiactive, acid, isohyperthermic
P6	Delta Telang II	Sulfic Hydraquent, fine, kaolinitic, nonacid, isohyperthermic
P7	Karang Agung Ulu	Sulfic Hydraquent, very fine, kaolinitic, nonacid, isohyperthermic

Mineralogical Composition

Sand fractions

Mineralogical composition of sand fractions of the tidal flat rice soils, represented by pedons P1, P4, and P7, is given in Table 3. The sand fraction is composed predominantly of quartz, and in decreasing order of smaller amounts are rock fragments, volcanic glass, andesine, orthoclase, sanidine, hypersthene, and oligoclase. Hornblende, augite, and albite are mostly present in very small amounts, or traces (less than 1%). Altogether, these latter minerals are often called weatherable minerals.

The presence of dominant quartz, rock fragments, volcanic glass, and minerals of K-Na-feldspars, such as andesine, orthoclase, and sanidine, suggests that marine sediment as the parent material of the tidal flat rice soils has its origin from the weathering of acid volcanic products, probably of a rhyolitic character. The sediments carried by the Musi and latter Sugihan Kanan river as sediment loads were eventually deposited in the marine environment. Pedon P1 (Delta Upang) and P4 (Sugihan Kanan), with relatively high contents of weatherable minerals, seem to derived from this origin.

The sand fraction minerals of pedon P7 (Karang Agung Ulu) almost entirely consist of quartz (87-97%), opaque minerals (5-13%), and a very small amount of volcanic glass and K-Na-feldspars. This suggests that the sediment that formed the soils, originated from the weathering products of acid sedimentary rock, probably of quartz sandstone, with some mixture of weathering of acid volcanic products.

Differences in the content of weatherable mineral in the soils studied are thought due to differences in the sources of sediment materials. Generally, the content of weatherable minerals decreases from pedon P1, P4 to pedon P7. In terms of natural fertility, pedon P1 (Delta Upang) is the richest and pedon P7 (Karang Agung Ulu) is the poorest.

Clay fractions

Analyses of the composition of clay minerals using XRD are presented in Table 4 and Fig. 2. The results indicate that clay fractions contain kaolinite, smectite and illite, as well as primary quartz and crystoballite. In all pedons and in both surface and subsurface horizons to a depth of about 130 cm, kaolinite forms the largest component of the clay fraction, mixed with small to moderate amounts of smectite and illite.

Table 3. Percentage of different mineral types in sand fractions of the pedons P1 (Delta Upang), P4 (Sugihan Kanan), and P7 (Karang Agung Ulu), Musi Banyuasin, South Sumatra.

Depth (cm)	Mineral type (% total)												
	Op	Qu	Wm	Rf	Vg	Alb	Olg	And	Or	San	Hor	Aug	Hp
Pedon P1 (Delta Upang)													
0-9/15	1	80	1	10	2	-	1	3	tr	1	tr	-	1
9/15-36	2	65	1	11	4	tr	1	10	1	2	tr	-	3
36-65	2	49	5	16	5	tr	1	16	3	1	1	tr	1
65-116	1	47	8	22	8	-	tr	8	3	tr	1	tr	2
116-150	1	25	18	24	16	tr	tr	11	3	1	tr	tr	1
Pedon P4 (Sugihan Kanan)													
0-12	2	58	34	4	1	-	-	tr	tr	1	-	-	tr
12-31	1	87	2	6	3	-	tr	tr	1	tr	tr	tr	tr
31-73	2	83	1	3	7	-	tr	2	tr	1	tr	1	tr
73-95	1	71	1	10	13	-	-	3	1	tr	tr	tr	tr
95-130	1	67	2	14	7	-	tr	2	3	3	1	-	tr
Pedon P7 (Karang Agung Ulu)													
0-16	tr	90	3	3	1	-	1	2	-	-	-	1	tr
16-40	tr	97	tr	3	tr	-	tr	tr	-	tr	tr	tr	tr
40-90	13	87	-	tr	tr	-	tr	-	-	tr	tr	tr	tr
90-13	5	95	tr	tr	tr	-	tr	-	-	tr	-	-	tr

Mineral type: Op = opaque, Qu = quartz, Wm = weathered mineral, Rf = rock fragment, Vg = volcanic glass, Alb = albite, Olg = oligoclase, And = andesine, Or = orthoclase, Sa = sanidine, Hor = hornblende, Aug = augite, Hp= hypersthene; tr = < 1%

Table 4. Clay mineral composition of the tidal flat rice soils, Musi Banyuasin, South Sumatra.

Pedon	Depth (cm)	Kaolinite	Smectite	Illite	Quartz	Crystoballite
Pedon P1 (Delta Upang)						
Oa[1]	0-9/15	+++	+	+	++	+
Bg	9/15-36	+++	+	+	++	(+)
BCg	36-65	++	++	+	++	(+)
Cg	65-116	++	++	+	+++	(+)
Pedon P2 (Delta Saleh)						
Ap	0-26	+++	+	+	+++	(+)
Bg	26-48	+++	+	+	+	- -
Cg	48-65	+++	+	+	+	- -
2Cg1	65-98	+++	+	+	+	- -
Pedon P3 (Sugihan Kiri)						
Oa1[1]	0-15	++++	(+)	(+)	+	- -
Oa2[1]	15-40	++++	+	+	++	- -
Cg1	40-65	+++	++	+	++	(+)
Cg2	65-110	++	++	+	(+)	(+)
Pedon P4 (Sugihan Kanan)						
Ap	0-12	+++	+	+	(+)	- -
Bg1	12-31	+++	++	+	(+)	- -
Bg2	31-73	+++	++	+	+	- -
Cg1	73-95	+++	++	+	- -	- -
Pedon P5 (Delta Telang-I)						
Ap	0-19	+++	+	+	+	(+)
Bg1	19-46	+++	+	+	+	- -
Bg2	46-72	++	++	+	+	- -
BCg	72-110	++	++	+	- -	- -
Pedon P6 (Delta Telang-II)						
Ap	0-16	+++	+	+	(+)	(+)
Cg1	16-45	+++	+	+	++	(+)
Cg2	45-66	+++	+	+	- -	(+)
Cg3	66-108	+++	+	+	+++	- -
Pedon P7 (Karang Agung Ulu)						
Ap	0-16	+++	+	+	- -	- -
Cg	16-40	+++	+	+	(+)	- -
2Cg1	40-90	+++	+	+	(+)	- -
2Cg2	90-130	+++	++	+	(+)	- -

++++ = dominant, +++ = many, ++ = moderate, + = few, (+) = very few,
- - = not detected

[1]Composition of the clay fraction of organic soil material

The presence of kaolinite is indicated by a diffraction peak of around 7.18Å, smectite by diffraction peak of around 16Å that expands to about 18-21Å upon glycerol solvation, and illite by diffraction peaks that remain at 10Å on different treatments. The presence of crystoballite indicates the influence of volcanic materials.

It seems that both kaolinite and quartz came from weathering processes in the hinterland area, which were then transported and deposited in the marine environment. Kaolinite can also be formed from smectite weathering that is unstable in acid condition (Ismail, 1970). All pedons are derived from marine sediments, and it is deduced that smectite was formed at the time when the environment was still in natural condition, with neutral soil pH and plenty of bases and silica.

Environmental changes, both by means of lowering ground water and oxidization of sulfidic materials, cause the soils to become acid to very acid. In very acid conditions, smectite is unstable, then releases cations and loosing silica, eventually forming

Fig. 2. X-ray diffractogram of clay fraction of P1 (Delta Upang) and P7 (Karang Agung Ulu), Musi Banyuasin, South Sumatra.

kaolinite. It is difficult to distinguish whether kaolinite in these soils was formed from weathering of smectite or from sedimentation processes. The presence of quartz in the clay fraction supports the deduction that the parent material was originated from weathering of acid volcanic and sedimentary rocks.

The clay mineral composition of the tidal flat rice soils from Musi Banyuasin is slightly different with at of the tidal flat soils from Pulau Petak area, South Kalimantan. In Pulau Petak area, besides the normal kaolinite, vermiculite and secondary chlorite were also present, and crystoballite was not found (Prasetyo, 1995).

The presence of smectite in a very acid condition, such in acid sulphate soils, causes a real problem. In soil environments with a neutral pH, smectite is stable and maintains support to CEC. However, if the pH drops to become excessively acid, as the result of sulfidic material oxidation, smectite and eventually also kaolinite become unstable. Their alumino-silicate structure is gradually destroyed, and a lot of aluminum is released into soil solution. Further on, Al ions replace exchangeable bases (Ca, Mg, K) in the exchange complex of the nearby soil mass, and exchangeable basis are finally leached out by the incoming water, both vertically and horizontally. As a result, productivity of acid sulphate soils is commonly very low, due to the presence of excessive acidity, high content of soluble Al, Fe, and Mn, low availability of nutrients particularly P and K, and very low base saturation.

Chemical Properties

General chemical characteristics

Most pedons characteristically exhibit clay to silty clay texture with high content of clay fractions (>50%), and thus have fine to very fine particle size class (Table 5). Some pedons that commonly occupy former oxbow lakes, such as pedon P6, show slightly coarser texture, for instance silty clay loam, however they are still grouped into fine particle size class. This supports the postulate that the soils actually developed from fine to very fine textured sediments.

Organic carbon content of the surface peat layer (Oa) of pedons P1 and P3, and of the peaty plow layer (Ap) of pedons P2 and P4 are very high. Their organic carbon contents in the subsurface layers to a depth of about 150 cm, generally remain high to very high. In the unripe subsoils, the content of organic carbon commonly increases. Organic carbon contents of the plow layer of pedons P5, P6, and P7 are generally still high. Their contents in the subsurface layers however, vary from medium to very high. With increasing depth, their contents may decrease or increase irregularly, and in the unripe bottom layers the content always drastically increases. The irregular contents of organic carbon with increasing depth are evidences that different materials have been successively deposited during formation of sediment, that later became the parent material of the present soils.

Potential P content (P_2O_5 by 1 N HCl 25%) of most pedons ranges from very low to medium. The trend is that the surface plow layer generally contains higher P content than the subsurface layers. In the subsurface layers, the content of P does not follow a specific pattern, it may decrease or increase, but the content generally still varies from very low to medium. The high P content in the plow layer of pedons P3 and P4 (rice fields) is assumed to be a residue of phosphate fertilizer left in the soils.

Potential K content (K_2O by 1 N HCl 25%) of the upper layers that are ripe to nearly ripe, ranges from very low to medium. No specific pattern occurs; the surface layer may be higher or lower in the K content than the subsurface layers. The K content of the bottom layers, that are half-ripe to unripe, ranges from medium to very high. The trend is that the unripe bottom layers mostly contain the highest content of potential K. This may be due to the influence of salts of the marine environment during formation of sediments.

The available P content (by Bray-1 extraction) in all pedons ranges from very low to low, in both surface and subsurface layers. No specific trend occurs; surface layer may have lower or higher P than the subsurface layers. The very high content of available P in topsoils of pedons P3 and P5 is also thought due to the fertilizer residue left in the rice field soils.

Results from the analyses of topsoil samples indicate that the soils studied exhibit P retention that ranges from 56 to 97%. In normal upland soils, phosphate retention is usually correlated with the amorphous Al and Fe extracted by acid ammonium oxalate. Relation between these Alo and Feo in the studied tidal flat soils is illustrated in Fig. 3. In these soils, P retention seems to be more strongly correlated with Alo (r^2 = 0.73) than with Feo (r^2 = 0.27). The high values of P retention positively correlated with aluminum from amorphous materials. This result is similar with the results of a study on rice fields of West Java and East Java (Prasetyo *et al.*, 1996; Prasetyo *et al.*, 1997).

Table 5. Particle size distribution, organic carbon, potential P and K, and available P of the tidal flat rice soils, Musi Banyuasin, South Sumatra.

Depth (cm)	Particle size distribution (%) Sand	Silt	Clay	Texture/ PSC	Organic carbon (%)	25% 1 N HCl P_2O_5 (mg 100 g^{-1} soil)	K_2O (mg 100 g^{-1} soil)	Phosphate (Bray 1) (ppm)
Pedon P1 (Delta Upang)								
0-9/15	na	na	na	—	13.26	21	8	9.3
9/15-36	6	29	65	C/VF	3.06	8	16	2.9
36-65	8	31	61	C/VF	4.62	14	49	3.2
65-116	3	37	60	C/VF	4.89	25	63	7.2
116-150	3	50	47	SiC/F	4.01	36	87	16.6
Pedon P2 (Delta Saleh)								
0-26	na	na	na	—	7.60	39	14	32.8
26-48	16	30	54	SiC/F	2.57	6	10	9.6
48-65	17	29	54	C/F	3.72	6	17	4.5
65-98	11	31	58	C/F	7.61	13	58	3.7
98-140	10	34	56	C/F	4.86	30	90	6.5
Pedon P3 (Sugihan Kiri)								
0-15	na	na	na	—	14.22	229	23	137.7
15-40	na	na	na	—	20.76	41	17	44.4
40-65	4	40	56	SiC/F	2.08	5	16	13.1
65-110	6	39	55	C/F	6.83	18	45	7.3
110-150	6	37	57	C/F	6.45	20	63	10.9
Pedon P4 (Sugihan Kanan)								
0-12	na	na	na	—	8.33	268	53	9.7
12-31	1	28	71	C/VF	6.17	5	16	5.3
31-73	0	31	69	C/VF	4.33	7	39	4.7
73-95	1	44	55	SiC/F	2.74	21	76	15.1
95-130	1	56	43	SiC/F	1.95	28	99	14.7
Pedon P5 (Delta Telang I)								
0-19	1	45	54	SiC/F	4.53	28	9	89.4
19-46	1	35	64	C/VF	1.66	7	11	11.3
46-72	0	35	65	C/VF	1.58	4	11	8.5
72-110	2	40	58	SiC/F	1.80	5	11	8.7
110-150	10	57	33	SiC/FiSi	3.00	15	31	4.7
Pedon P6 (Delta Telang II)								
0-16	14	49	37	SiCL/F	3.80	10	7	9.2
16-45	15	49	36	SiCL/F	3.20	5	7	10.8
45-66	16	49	35	SiCL/F	3.75	3	8	14.0
66-108	15	49	36	SiCL/F	7.49	3	11	6.4
108-140	14	49	37	SiCL/F	8.53	3	15	2.9
Pedon P7 (Karang Agung Ulu)								
0-16	0	35	65	C/VF	4.09	41	20	15.6
16-40	0	32	68	C/VF	1.43	7	24	5.4
40-90	1	32	67	C/VF	5.33	13	54	7.4
90-130	1	31	68	C/VF	5.99	17	83	13.1

na = not analysed; C = clay; SiC = silty clay; SiCl = silty clay loam; VF = very fine; F = fine

Exchangeable cations and cation exchange characteristics of the studied soils are presented in Table 6. In all pedons, the general trend of exchangeable cations is that Mg is the dominant cation, followed in decreasing order by Na, Ca, and K. The high content of Mg and Na cations reflects the influence of salts from sea water of the tidal flat environment. The ratios of Ca/Mg that always less than 1 in all surface and subsurface layers support the postulate that soils are actually developed from marine sediment. This situation also indicates an unbalance nutrient condition, because in common agricultural soils, Ca content is normally higher than Mg content.

In term of the amount of exchangeable cations, Mg content mostly varies from high to very high in all

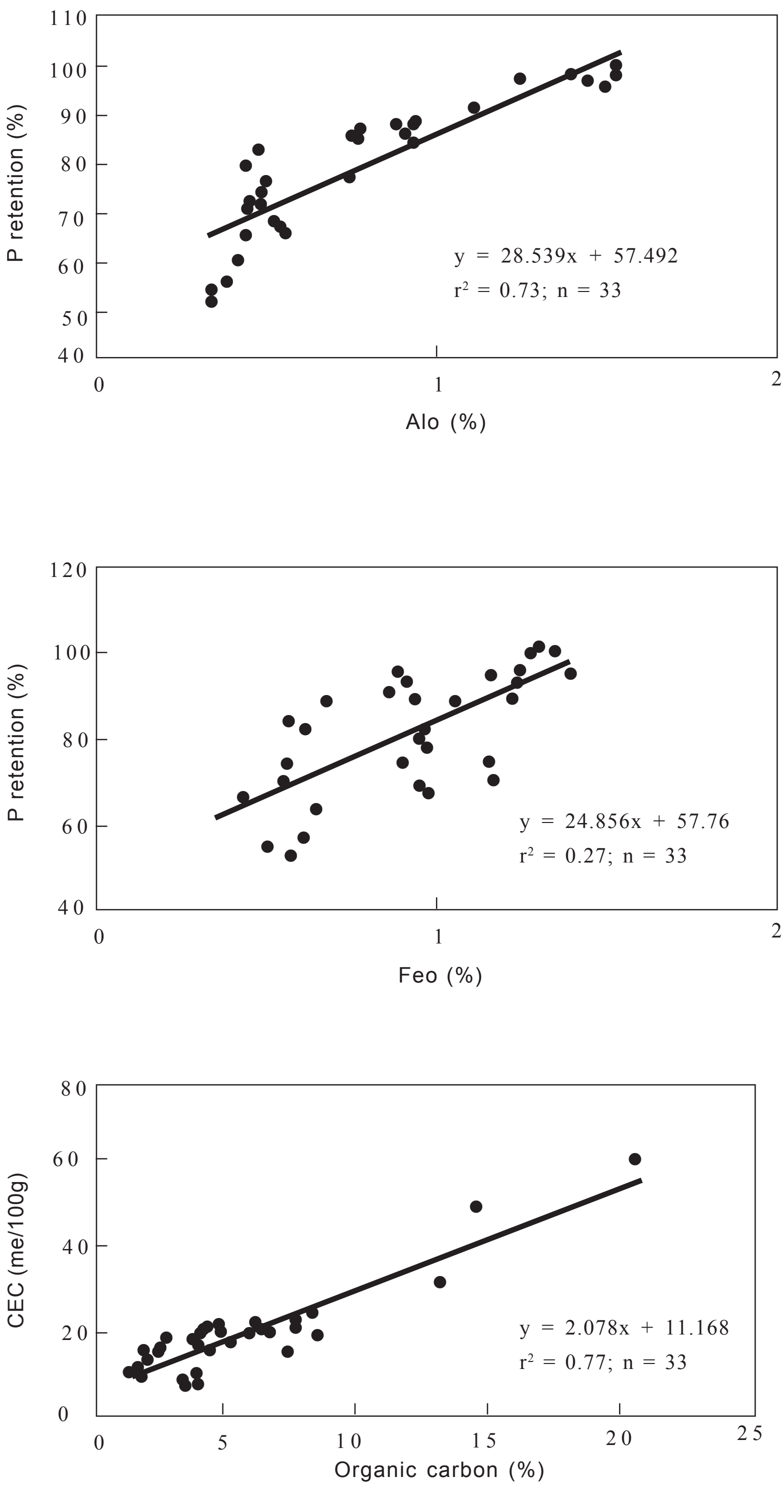

Fig. 3. Relationships between phosphate retention with amorphous Alo and Feo, and of CEC vs. organic carbon of tidal flat areas of Musi Banyuasin, South Sumatra.

Table 6. Exchangeable cations, base saturation, and cation exchange capacity of rice soils of the tidal flat area, Musi Banyuasin, South Sumatra.

Depth (cm)	Exchangeable cations					Base saturation	CEC	
	Ca	Mg	K	Na	Total		Soil	Clay
	..........................(cmol(+) kg^{-1} soil).........................					(%)	(cmol(+) kg^{-1}soil)	
Pedon P1 (Delta Upang)								
0-9/15	1.64	4.41	0.11	0.71	6.87	21	32.3	51.2
9/15-36	1.67	6.02	0.17	0.93	8.79	38	23.0	35.4
36-65	2.12	7.90	0.08	0.79	10.89	45	24.2	39.6
65-116	4.78	18.07	0.60	3.24	26.69	100	25.0	41.7
116-150	6.04	19.18	1.07	5.06	31.35	100	23.0	49.0
Pedon P2 (Delta Saleh)								
0-26	1.03	2.46	0.22	0.37	4.08	18	22.8	47.5
26-48	2.27	6.34	0.08	0.74	9.43	47	20.1	37.2
48-65	2.13	8.55	0.22	1.22	12.12	55	22.1	41.0
65-98	3.37	19.08	0.33	3.38	26.16	100	25.0	43.1
98-140	4.36	20.86	0.89	5.64	31.75	100	23.9	42.7
Pedon P3 (Sugihan Kiri)								
0-15	5.81	6.39	0.21	0.31	12.72	26	49.6	71.8
15-40	7.50	9.84	0.28	1.41	19.03	31	60.5	144.1
40-65	3.54	8.75	0.25	0.62	13.16	73	18.1	32.4
65-110	1.03	16.59	0.51	5.30	23.43	100	23.4	42.6
110-150	3.28	20.09	0.70	6.94	31.01	100	23.7	41.6
Pedon P4 (Sugihan Kanan)								
0-12	0.32	0.47	0.78	0.13	1.70	6	26.4	52.9
12-31	0.85	2.43	0.25	0.25	3.78	15	25.0	35.2
31-73	1.66	5.45	0.21	1.02	8.34	34	24.8	35.9
73-95	1.22	14.88	0.13	3.52	19.75	96	20.6	37.5
95-130	5.73	24.51	1.00	6.42	37.66	100	20.8	37.1
Pedon P5 (Delta Telang I)								
0-19	2.02	3.59	0.08	0.39	6.08	32	19.3	35.7
19-46	1.85	4.87	0.16	0.55	7.43	46	16.2	25.3
46-72	2.44	6.46	0.16	0.49	9.55	55	17.4	26.8
72-110	2.47	6.79	0.16	0.46	9.88	74	13.4	23.2
110-150	3.66	8.71	0.24	0.59	13.20	100	12.1	36.7
Pedon P6 (Delta Telang II)								
0-16	1.07	1.71	0.48	0.48	3.74	32	11.6	31.3
16-45	0.91	1.69	0.08	0.60	3.28	29	11.2	31.1
45-66	1.30	2.65	0.14	0.96	5.05	37	13.6	38.9
66-108	1.42	3.21	0.12	1.60	6.35	37	17.4	35.4
108-140	3.54	7.90	0.17	2.86	14.47	71	20.5	55.4
Pedon P7 (Karang Agung Ulu)								
0-16	3.81	8.19	0.22	4.63	16.85	84	20.1	30.9
16-40	2.84	8.50	0.24	3.62	15.20	94	16.3	23.9
40-90	4.07	14.63	0.58	5.25	24.53	100	21.3	31.8
90-130	5.31	19.37	0.88	6.96	32.52	100	22.1	32.4

layers. Na content ranges from medium to very high, and tends to be higher in the unripe bottom layers. All Ca content varies from very low to low, with no specific pattern of distribution among different layers. K content ranges from low to high, and the bottom, unripe layers tend to have higher content. The distribution pattern of total exchangeable cation similar to Na cations. The amount of total exchangeable cations ranges from low to medium in the ripe to nearly ripe upper layers, and mostly becomes medium to very high in the unripe bottom layers.

The pattern of distribution of base saturation is again similar to total exchangeable cations. In the upper, ripe to nearly ripe layers to a depth of about 65-100 cm, base saturation varies from very low to medium. Below this depth, where sulfidic materials are found and soils is still in unripe condition, base saturation are high to very high, and in many layers base saturation values of 100% are often found.

In all pedons, the CEC value seems highly variable, and without definite pattern of distribution. In some pedons, such as pedon P1, P3, and P4, the CEC values range from medium to high or very high, and medium in the lower layers. In the other pedons, i.e., pedons P5, P6, and P7, the CEC values vary from low to medium, with the upper layers contain higher or lower CEC values than the bottom layers.

The very high CEC value of the pedon P3 topsoil is caused by its high organic matter (peat). CEC is known to be highly correlated with the content of organic matter in the soils, as indicated by the relation between organic carbon (%) and soil CEC values, that shows a coefficient correlation (r^2) = 0.77) (Fig. 3). A similar result was also reported from a study of soil development derived from fluvio-marine deposits in East Kalimantan (Prasetyo *et al.*, 1999).

The CEC of clay fraction that is counted without organic matter correction (Table 6) generally ranges from high to very high, CEC values that better fit soils with mixed mineralogy. However, since the dominant component of clay is kaolinite, with some mixture of smectite, the high values of clay-CEC are thought to be caused by CEC contribution coming from organic matter and smectite mineral.

Specific chemical characteristics

Specific chemical properties of the studied tidal flat soils are presented in Table 7. Specific chemical properties are the characteristics of soils in the tidal flat areas that are influenced by the presence of sulfidic materials. Oxidation of sulfidic materials causes soil pH to drops so it may become excessively acid, with the result exchangeable Al and water-soluble sulphate increase.

Soil pH on fresh soil samples at the field condition for most pedons, except pedon P4 which is an acid sulphate soil (Typic Sulfaquept), exhibits pH values of 4.5 or greater (Table 7). The upper, ripe to half-ripe horizons show pH values between 4.5 and 5.5, that is very strongly acid to strongly acid. The bottom unripe layers exhibit higher pH values that range from 6.0 to 8.0, which is slightly acid to moderately alkaline.

However upon exposed approximately 1-2 months after being taken from the field, the fresh and the remaining sulfidic materials in different layers were oxidized, and laboratory pH measurement on these oxidized samples yields lower pH values. The higher the content of the remaining sulfidic materials in the soil mass, the lower the pH drops. Thus after 1-2 months, pH values of any horizon in most pedons drops to 4.5 or lower. No difference in pattern was seen between the upper ripe and the bottom unripe layers. The higher the content of water soluble sulphate, as measure of the content of sulfidic materials, the lower the drop in pH value. As seen in some horizons in pedons P1, P2, P4, and P6, pH values less than 3.5 (pH ranges 2.6-3.2) are correlated with water soluble sulphate contents of about 0.70% or greater.

The presence of sulfidic materials can be deduced from the content of water soluble sulphate, and also partly supported by total sulphur content. Soil Survey Staff (1999) sets a value of 0.05 % of more water soluble sulphate as evidence for the presence of sulfidic materials.

From this value, it can be inferred that most pedons, except pedon P5 (Delta Telang), have layers containing sulfidic materials within 100 cm of the mineral soil surface, and generally starting around 65 cm. Pedon P5, uniquely does not have sulfidic materials within 150 cm of the mineral soil surface. This probably can be explained by the good water management of the rice fields, such that toxic products of sulfidic materials oxidation can be washed out from the soil environment efficiently. On the contrary, the main reason of formation of acid sulphate soil of pedon P4 (Sugihan Kanan), is thought to be because of the poor drainage system and incorrect water management. Toxic compounds from sulfidic material oxidation cannot leave the soils, and gradually accumulate in the soil rooting system.

Water soluble sulphate has a correlation with soil pH and total sulphur, and correlation with total sulphur is stronger than with soil pH (H_2O). Figure 4 shows that the increasing water soluble sulphate is positively correlated (r^2 = 0.78) with total sulphur in the soil, while water soluble sulphate showed a negative correlation (r^2 = 0.51) with soil pH. A similar result was reported by Prasetyo *et al*. (1999) on soils derived from fluvio-marine deposit.

The contents of exchangeable Al and H in most pedons are considered high to extremely high, since in a normal soil, such as in an Oxisol, exchangeable

Table 7. pH, exchangeable acidity, water-soluble sulphate, and total sulphur of rice soils of tidal flat areas, Musi Banyuasin, South Sumatra.

Depth (cm)	Field-soil-pH	Lab.-soil pH pH (1:2.5)		Exchangeable acidity		Water-soluble sulphate	Total sulphur
	H_2O	H_2O	KCl	Al	H		
				(cmol(+) kg^{-1} soil)		(%)	
Pedon P1 (Delta Upang)							
0-9/15	5.0	4.0	3.6	6.59	0.93	0.005	0.05
9/15-36	5.0	3.6	3.2	9.18	0.91	0.008	0.19
36-65	5.0	2.6	2.4	25.79	10.62	0.080	0.60
65-116	6.0	3.5	3.2	5.52	4.32	0.066	0.42
116-150	6.0	4.8	4.3	0.26	0.65	0.052	0.36
Pedon P2 (Delta Saleh)							
0-26	4.5	4.5	3.9	4.65	0.92	0.003	0.02
26-48	5.0	4.2	3.6	5.21	0.96	0.005	0.02
48-65	5.0	3.7	3.3	7.21	0.96	0.002	0.12
65-98	6.5	3.1	2.9	11.81	11.97	0.071	0.35
98-140	6.5	3.8	3.5	3.07	4.92	0.070	0.33
Pedon P3 (Sugihan Kiri)							
0-15	5.5	4.4	3.7	4.55	0.63	0.003	0.18
15-40	4.5	4.7	3.9	3.10	0.59	0.004	0.15
40-65	5.5	5.1	3.9	1.19	0.22	0.003	0.02
65-110	7.0	3.6	3.2	2.95	4.13	0.050	0.46
110-150	8.0	3.8	3.4	2.18	4.00	0.063	0.41
Pedon P4 (Sugihan Kanan)							
0-12	4.5	4.0	3.9	6.56	0.69	0.005	0.05
12-31	4.0	3.6	3.3	13.81	1.04	0.005	0.28
31-73	3.0	3.2	3.0	18.54	1.11	0.035	0.34
73-95	6.5	3.1	2.9	16.05	3.45	0.070	0.50
95-130	7.0 3	.7	3.4	5.09	2.67	0.075	0.38
Pedon P5 (Delta Telang I)							
0-19	5.5	4.5	3.7	4.88	0.86	0.003	0.03
19-46	5.0	4.4	3.6	6.33	0.79	0.002	0.05
46-72	5.0	4.5	3.6	6.26	0.72	0.002	0.04
72-110	5.0	4.3	3.5	4.3 8	0.66	0.004	0.14
110-150	7.0	4.0	3.6	1.19	2.11	0.030	0.56
Pedon P6 (Delta Telang II)							
0-16	5.0	4.4	3.7	4.29	0.78	0.002	0.02
16-45	4.5	4.6	3.7	4.69	0.82	0.001	0.07
45-66	4.5	4.3	3.7	5.22	0.84	0.004	0.20
66-108	7.0	3.0	2.9	12.54	6.17	0.060	0.67
108-140	7.0	2.9	2.8	12.54	12.88	0.077	0.65
Pedon P7 (Karang Agung Ulu)							
0-16	4.5	5.1	4.2	0.83	0.13	0.001	0.10
16-40	5.0	4.6	3.7	2.24	0.52	0.002	0.03
40-90	6.5	4.1	3.6	1.20	2.80	0.038	0.42
90-13	6.5	4.2	3.8	1.09	1.32	0.054	0.38

Al of more than 2 cmol (+) kg^{-1} soil is already considered high. The origin of Al ions as already explained is coming from the release of Al upon destruction of alumino-silicate lattice of clay mineral due to excessively acid soil conditions. The high availability of Al and also Fe^{2+} ions coming from oxidation of sulfidic materials, causes very high fixation capacity for phosphate, as another common

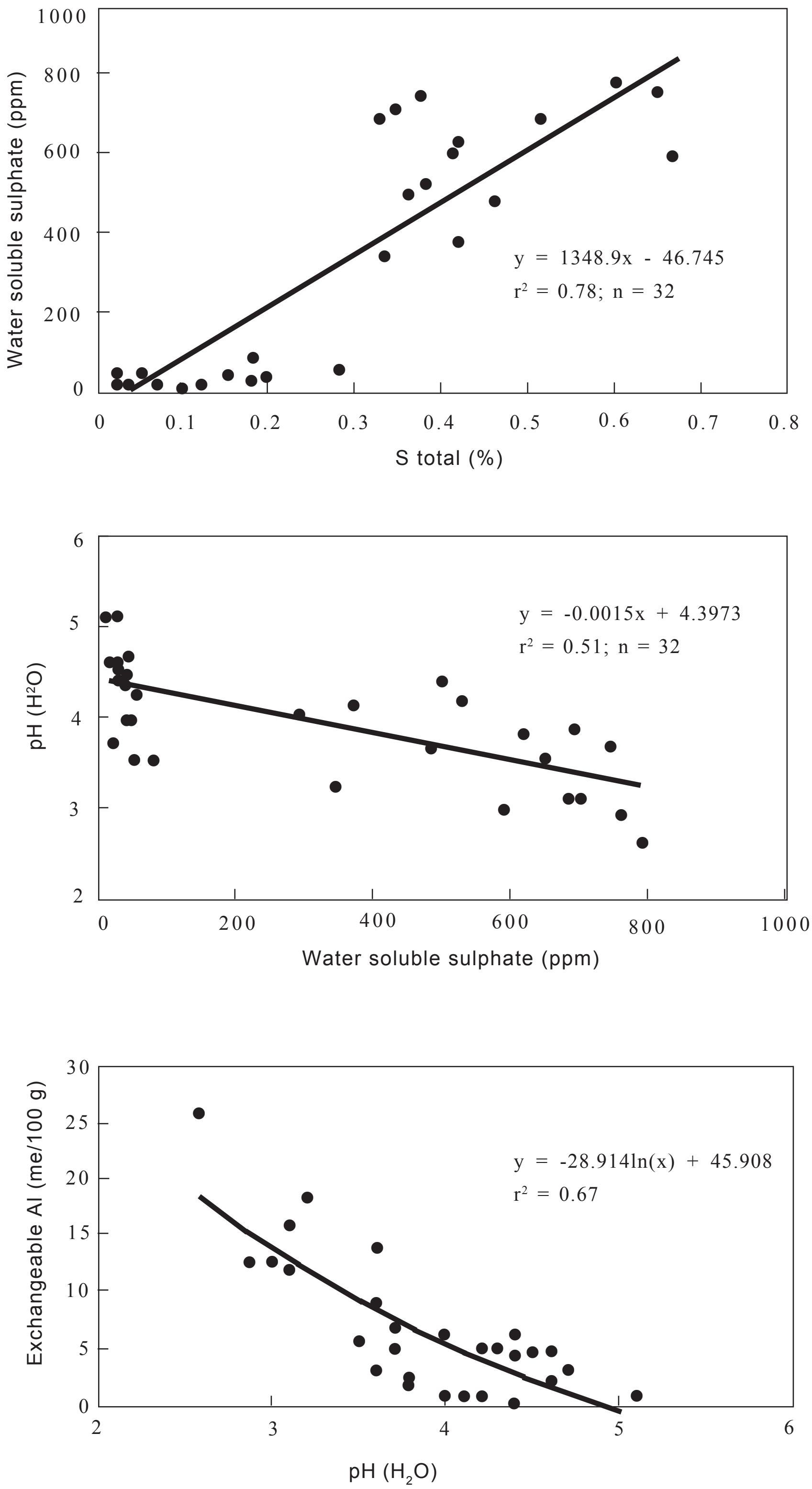

Fig. 4. Relationships between water soluble sulphate and total sulphur, water soluble sulphate vs. pH (H_2O), and exchangeable Al vs. pH (H_2O).

characteristic of tidal flat soils. Exchangeable Al is negatively correlated ($r^2 = 0.62$) with soil pH (H_2O), as shown in Fig. 4. Thus a decreasing pH results in an increasing amount of exchangeable Al. Above pH 5.0, the amount of exchangeable Al is negligible in the soil.

The tidal flat soils actually have potential for agricultural development, as proved by presently available vast areas of tidal swamp rice fields in Musi Banyuasin area. However, productivity varies greatly among locations. Tidal flat rice soils of Delta Upang, Delta Saleh, and Delta Telang I, that mostly have sulfidic materials between 50 and 100 cm, and particularly between 100 and 150 cm of the mineral soil surface, are among the best tidal flat rice fields in the area (Badan Penelitian dan Pengembangan Pertanian, 1998). However, tidal flat soils always show some constraints or limiting factors that should be solved, if to be used for agriculture. One of the common limiting factors is the excess of Al and Fe^{2+} in soil solution (Ponnamperuma, 1972), and high P fixation as the result of interaction between phosphate ion with both Al and Fe^{2+} ions (Rorison, 1973). According Van Breemen (1976), Al concentration in soil increases up to ten times for every decrease to one unit pH value. Inundating the soil increases Fe^{2+} to a toxic level for rice growth (Moormann and Van Breemen, 1978; Van Mensvoort *et al.*, 1985). In poor plant nutrition conditions, 30 ppm concentration of Fe^{2+} is already toxic for rice plant (Van Breemen and Moormann, 1978).

CONCLUSIONS

The rice soils of the tidal flat areas are generally poorly drained, show grey colored profile, and have properties related to aquic soil conditions. Some pedons exhibit a thin peaty layer on the surface, and most have an Ap horizon with high organic matter content. Some are remnants of thick peat soils (Histosols) where the peat thickness has decreased to less than 50 cm, due to agricultural uses after 20-25 years, and therefore soils have a histic epipedon. The presence of sulfidic materials in the subsoils was proved by the H_2O_2 test, mostly, present at a depth between 50 and 100 cm below mineral soil surface. Only rice soils in Delta Telang I (pedon P5) do not show the presence of sulfidic materials within 150 cm of the mineral soil surface. Pedon P4 that is probably developed in excessive drainage and poor water management has formed into an acid sulphate soil, with a soil pH at a depth of 30-70 cm.

Four pedons are classified as Inceptisols, i.e., Typic Endoaquepts (P1 and P2), Fluvaquentic Endoaquept (P5), and Typic Sulfaquept (P4), while the other three pedons are classified as Entisols, i.e. Histic Sulfaquent (P3) and Sulfic Hydraquent (P6 and P7). All pedons have fine to very fine particle size class, and either kaolinitic or mixed mineralogy. The results of classification tend to conclude that distance from the sea seems not to have an influence on rice soil development. Local topography, hydrology, and drainage systems probably play significant roles.

The mineralogical composition of sand fractions is dominated by quartz, while the clay fractions are mostly dominated by kaolinite with some mixture of smectite and illite. Differences in the content of weatherable minerals reflect differences in the sources of sediment.

General chemical characteristics show that there are some differences in the content of organic matter, P and K potential, as well as available P between the upper, ripe to nearly ripe soil and the bottom, half-ripe to unripe subsoils. P retention is high and seems to be affected by amorphous aluminum in soils. Ratios of Ca/Mg are less than one, supporting the deduction that the soils are actually developed from marine sediment. The CEC values are mostly medium and influenced by organic carbon and smectite mineral.

Specific chemical properties indicate a significant change of soil pH 1-2 months after being taken from the field. Depth and presence of sulfidic material can be proven by H_2O_2 field test, supported by the content of water soluble sulphate that is greater than 0.05 %. The contents of exchangeable Al and H are considered high to very high.

Tidal flat rice soils are actually potential for agricultural development, but productivity significantly varies among locations. One important limiting factor, i.e., excess of Al and Fe^{2+}, and other toxic compounds resulting from oxidation of sulfidic materials must be able to be washed out from the soil environment. Theoretically, good interaction between proper water management and fertilizer application is among the management solution available to make these soils productive.

REFERENCES

Badan Penelitian dan Pengembangan Pertanian. 1998. Prospek pengembangan sistem usaha pertanian modern di lahan pasang surut Sumatera Selatan. Proyek Pengembangan Sistem Usaha Pertanian Lahan Pasang Surut Sumatera Selatan, Badan Penelitian dan Pengembangan Pertanian, Jakarta. 251 hlm.

Badan Penelitian dan Pengembangan Pertanian. 1999. Identifikasi dan karakterisasi wilayah pengembangan sistem usaha pertanian lahan pasang surut Sumatera Selatan. Tahap II. Proyek Pengembangan Usaha Pertanian Lahan Pasang Surut Sumatera Selatan. Badan Penelitian dan Pengembangan Pertanian, Jakarta. 243 hlm.

Blackmore, L.C., P.L. Searle, and B. K. Daly. 1981. Methods for chemical analysis of soil. NZ Soil Bureau Sci. Rep. 10A. Soil Bureau, Lower Hutt, New Zealand.

Departemen Pekerjaan Umum. 1998. Pengembangan Daerah Rawa. Direktorat Jenderal Pengairan, Departemen Pekerjaan Umum, Jakarta. 93 hlm.

Ismail, F.T. 1970. Biotite weathering and clay formation in arid and humid region of California. Soil Sci. 109: 257-261.

Janssen, J.A.M., B.H. Prasetyo, and Alkusuma. 1990. Acid sulphate soils: field characteristics and mapping. p. 51-61. Paper Workshop on Acid Sulphate Soils in the Humid Tropic. AARD in cooperation with Lawoo, Jakarta.

Moormann, F.R., and N. Van Breemen. 1978. Rice: soil, water, land. Intern. Rice Res. Inst. Los Banos.

Oldeman, L.R., Irsal Las, and S.N. Darwis. 1979. An agroclimatic map of Sumatra. Contr. Centr. Res. Inst. Agric., Bogor, No. 52. 35 pp.

Ponnamperuma, F. N. 1972. The chemistry of submerged soils. Adv. Agron. 24: 29-98.

Prasetyo, B. H. 1995. Mineral pada tanah sulfat masam di Pulau Petak, Kalimantan Selatan. hlm. 86-91. *Dalam* H.H. Djohar, (Ed.). Risalah Seminar Hasil Penelitian Tanah dan Agroklimat No 2, Pusat Penelitian Tanah dan Agroklimat, Bogor.

Prasetyo, B.H., M. Soekardi, dan H. Subagyo. 1996. Tanah-tanah sawah intensifikasi di Jawa: Susunan mineral, sifat kimia dan klasifikasinya. Pemberitaan Penelitian Tanah dan Pupuk No. 14: 12-14.

Prasetyo, B.H., A. Suriya, B. Kaslan, dan M. Soekardi. 1997. Tanah-tanah yang berkembang dari bahan endapan fluvio-marin di daerah Karawang, Jawa Barat. Jurnal Tanah dan Iklim No. 15: 18-27.

Prasetyo, B.H., Hikmatullah, dan N. Suharta. 1999. Karakteristik tanah dari bahan endapan fluviatil dan marin di daerah pantai timur Samarinda-Balikpapan, Kalimantan Timur. hlm 147-166. *Dalam* I Las (Ed.). Prosiding Seminar Nasional Sumberdaya Lahan. Buku II. Pusat Penelitian Tanah dan Agroklimat, Bogor.

Puslittanak (Pusat Penelitian Tanah dan Agroklimat). 1989. Pemetaan tanah tingkat detail, skala 1:10.000 daerah pasang surut Karang Agung Tengah, Musi Banyuasin, Sumatera Selatan. Pusat Penelitian Tanah dan Agroklimat, Bogor.

Rorison, I.H. 1973. The effect of extreme soil acidity on the nutrient uptake and physiology of plants in acid sulphate soils. ILRI Publication 18. Vol. 1. Wageningen. The Netherlands.

Schmidt, F.H. and J.H.A. Ferguson. 1951. Rainfall types based on wet and dry period ratios for Indonesia, with Western New Guinea. Kementrian Perhubungan Djawatan Meteorogi dan Geofisika. Verh. No. 42. 77 hlm.

Soil Survey Laboratory Staff. 1991. Soil Survey Laboratory Methods Manual. SSIR Number 42. Version 1.0. United States Dept. of Agric, Washinton, DC. 611 pp.

Soil Survey Staff. 1999. Soil taxonomy. A basic system of soil classification for making and interpreting soil surveys. 2nd Edition. United States Dept. Agric., Natural Resources Conservation Service, Washington D.C.

Suryanto, W.J., H. Suganda, Basuni Hw., dan M. Soekardi. 1991. Keadaan tata air di daerah pasang surut dan permasalahannya (Studi kasus di Daerah Karang Agung Tengah, Sumatera Selatan). *Dalam* H. Suhardjo (Ed.) Prosiding Pertemuan Teknisi Penelitian Tanah dan Agroklimat. Bidang Karakterisasi dan Evaluasi Sumberdaya Lahan. Bogor, 3-5 Juni 1991.

Syukur E.K., M. Hikmat, Edi Yatno, dan H. Subagyo. 2000. Tipologi dan penataan lahan serta prioritas pengembangan lahan pasang surut di Karang Agung Tengah, Sumatera Selatan. Prosiding Seminar Nasional Reorientasi Pendaya-gunaan Sumberdaya Tanah, Iklim, dan Pupuk. Cipayung, Bogor, November 2000. Pusat Penelitian Tanah dan Agroklimat, Bogor.

Van Breemen, N. 1976. Genesis and solution chemistry of acid sulphate soils in Thailand. Agric. Res. Rep. 848, Pudoc. Wageningen.

Van Breemen, N. and R. Moormann. 1978. Iron toxic soils. *In* Intern. Rice Res. Inst.: Soil and Rice. IRRI, Los Banos.

Van Mensvoort, M.E., R.S. Lantin, R. Brinkman, and N. Van Breemen. 1985. Toxicity of wetland soil. p 123-138. *In* Intern. Rice Res. Inst. Wetland soils: characterization, classification and utilization. IRRI, Los Banos.