PYRITE-CONTAINING SEDIMENTS OF SOUTHERN KALIMANTAN, INDONESIA. THEIR SOILS, MANAGEMENT AND RECLAMATION

P.M.Driessen and Ismangun
Soil Research Institute
Bogor, Indonesia

Introduction

Along the southern coast of Kalimantan (formerly Borneo), a strip of 2.3 million hectares consists of marine and brackish water sediments, which are rich in pyrites. Locally these sediments are covered with fluviatile material, mainly as levees of a number of rivers coming from the central part of Kalimantan and debouching into the Java Sea.

At present only the southernmost part of the area with marine deposits is still under tidal influence and in this part (comprising some 150 000 ha), the genesis, management and reclamation of the soils are in fact governed by the tidal movement, as the following discussion indicates.

Soils

Three major groupings of genetically related soils are present in the tidal zone of southern Kalimantan: soils on fluviatile deposits, soils developed in marine sediments and organic soils.

They were studied in an area of approx. 16 000 ha, situated along the river Barito near Bandjarmasin. This area is representative for most of the tidal region of southern Kalimantan (see Fig.1).

The fluviatile deposits are most evident in levees close to the rivers. These levees - although morphologically hardly distinguishable - differ from the marine deposits by their chemical and physical properties. They consist mainly of clay and silty clay, as the coarser particles have already been sedimented north of the tidal zone. The shape of the river bed, widening towards the coast, and the consequently low velocity of the water, account for this. At present river sedimentation has stopped almost completely. The developed soils have shallow grayish-brown A-horizons (10 YR 3/2 to 5/2) over weak, dark-gray B-horizons (10 YR 4/1) or directly over a dark-gray (2.5 Y 4/0) permanently reduced C-horizon. They are classified as Tropaquents or Tropaquepts.

Although the presence of pyrites, originating from rewashed marine material, has been microscopically established, the good natural drainage of these soils, in combination with the high rainfall, prevents significant acidification. pH-values as estimated during field work by inserting a combination electrode directly into the soil, were about pH 5.8. Subsequent pH determinations in the laboratory resulted in slightly higher values, because of the absence of the suspension effect.

The fluviatile sediments overlay material of marine origin which has obviously been deposited in a tidal milieu with a typical halophytic/telmatophytic vegetation. Deeper than 1 metre below the land surface, relics of this vegetation are frequently found as plant tissues which did not decay because of the permanent anaerobic conditions at this depth. In places, the deep subsoil is greenish in colour (5 Y 4/1) because of chlorite, chamosite and possibly glauconite which are characteristic of marine material deposited in shallow sees under tropical climatic conditions (Porrenga 1967). The subsoils are rich in sulphides; shells and their fragments are absent at depths of less than three metres below the present surface.

The river deposits are locally covered by a shallow peat layer, especially at some distance (over 100 metres) from the river. The land dips gradually away from the rivers until at distances of 1 to 2 km the soils are developed in pure marine sediments. Depending on their location and water regime these soils are more or less acidified.

Where tidal movements are no longer noticeable e.g. in the central depression between two big rivers, the soils are entirely raindependent. Stagnant and very acid marshes occur there, which fall dry in years with low precipitation. The upper 60 cm of the soil is then aerated, which causes sudden oxidation of the pyrites and severe acidification. The acid formed is not entirely carried off in subsequent wet periods because of the poor natural drainage inherent to the low location of the area.

Under these conditions, acid (pH lower than 4.5) sulphate soils are formed which have shallow, very dark-gray (10 YR 3/1) A-horizons, locally covered by 10 to 20 cm of black (5 YR 2/1) hemic peat.

The A-horizon is underlain by an oxidized Bg-horizon with mottling of iron, jarosite and alum. Deeper than 1 metre the gray (10 YR 4/1) subsoil is permanently anaerobic. The absence of greenish colours in these subsoils is striking.

These soils are classified as Hydraquents, Tropaquents or Tropaquepts, the latter partly in the Hydric subgroup (see: Slager and Van Schuylenborgh 1970).

At short distances from rivers and water courses, where tidal movement is still significant, aeration of the soils proceeds gradually, resulting in slow oxidation of the pyrites. In addition the subsoil is rich in chlorite and chamosite which, upon disintegration, neutralize the slowly released acid (Pons 1970).

These factors, in combination with a fair natural drainage, have resulted in the formation of potential acid sulphate soils with pH-values between 4.5 and 5.5. The profile consists of a brownish to black (5 YR 2/2, 10 YR 2/1) A-horizon over a grayish (5 YR 4/1-10 YR 4/2) Bg. The subsoil has a characteristic gray to dark-gray colour to which chlorite and chamosite add a tinge of green (5 Y 4/1-5/1).

These soils are classified as Typic and Hydric Tropaquepts.

In the lowest parts of the tidal region fresh-water marshes occur, which are entirely rain-dependent. Primary marsh forest is found there on thick layers of mesotrophic, hemic and sapric peat.

The general processes described above are clearly illustrated by the soil map of the area studied, as presented in a simplified form in Fig.1. From west (pt B) to east (pt A) one finds a sequence from permanently waterlogged peat soils over poorly drained rain-dependent acid sulphate soils and slightly higher located potential acid sulphate soils to well-drained, non-acid soils on the river levee. Although relief is not very pronounced, the strict correlation between environmental conditions and soil properties (Fig.2) makes this sequence clearly recognizable on air-photos (see also Schwaar, 1970).

Management

Present soil management in the tidal region of southern Kalimantan is the result of centuries of experience gained by the Bandjarese population and Buginese immigrants. Adapted agricultural practises, plant varieties and water management are blended in a highly sophisticated agricultural system, which - in its traditional form - combines ingeneous soil conservation with the highest possible production. A close relation exists between environmental conditions and local crops and cultivation techniques.

On river levees, where acidification is negligeable and ground water is relatively deep, homestead gardens are found, as well as plantations. Rubber, coconut and tangerine give high yields there. Wet rice is not commonly grown within 1 km of the river, as tidal movement is too strongly felt and might damage the crop (Schophuys, personal communication).

At a distance of 1 to 7 km from the river tidal movements are less pronounced.

Longer inundations occur here and, due to the lower level of the terrain, water depths during flooding are considerable. This area roughly coincides with that of the potential acid sulphate soils discussed above.

To cope with the insufficient water control in this area the Bandjarese population developed a specific wet rice culture, known as "sawah bajar". It comprises 5 basic stages:

1. Soil Tillage

Normal tillage would inevitably lead to oxidation of pyrites, exposed to the air upon plowing. Tillage is therefore restricted to the shallow humous toplayer of the soil and consists of "peeling" the land with a scythe-like tool, known as a "tadjak" (Schophuys 1936; Noorsjamsi and Hidajat 1970). The weeds are used as a mulch and contribute to the preservation of the high organic matter content of this toplayer.

2. Preparation of seedbeds

Seedbeds are made in September-November on high parts of the area. The beds are very densely sown and kept under 5-8 cm of water. No weeding takes place during this stage.

3. First transplanting

After 1 month the seedlings are transplanted and the water depth is increased to approx. 10 cm. The beds are carefully weeded.

4. Second transplanting

After the water has fallen the rice is again transplanted, normally with 7 plants per hole, under 25 cm of water.

5. Third and last transplanting

The last transplanting takes place at about 4½ months after sowing with only 2 plants per hole in a 30 x 30 cm grid. Water depths up to 50 cm can then be withstood. The disadvantages of the laborious cultivation method and the long vegetation period are compensated for by a number of striking advantages:

- Bajar varieties need only a shallow surface layer free of noxious substances. Therefore, soil tillage can be restricted to the upper decimetre of the soil, which prevents soil acidification and conserves the soil.

- Because of the frequent transplantations, robust seedlings are obtained which can grow in deep water for long (inundation) periods.

- The high number of tillers obtained in this type of cultivation practice reduces the required seed to approx. 5 kg per hectare.

To a large extent "bajar" yields are determined by fertilizer application, pest control (rodents and Podops vermiculata) and hydrological conditions. In newly opened sawah land, crop yields are only 500 to 1000 kg of wet paddy per hectare. After a few years, however, acids and free Fe and Al are washed out of the surface soil and crop yields increase to 2500-3000 kg per hectare.

Near Bandjarmasin this yield increase was locally followed by a gradual decrease, possibly due to insufficient maintenance of canals and waterways. The latter results in decreasing tidal influence and may finally lead to stagnant water. In places subsidence of the land caused decreasing drainage and therewith increasing acidity and Al and Fe contents, reflected in a drop in crop yield to less than 1000 kg wet paddy per hectare (NEDECO 1965).

Particularly at a distance of 6 to 8 km from the river, where tidal influences are weak, abandoned sawahs are frequently encountered. Here lies the transition to the area with real acid sulphate soils which is occupied by low yielding sawahs (500-1000 kg/ha) and purun (Fimbristylis globulosa) and gelam (Melaleuca leucadendron) marshes.

At distances of some 10 to 15 km from the river cassava and pineapple are grown on thick peat soils.
These areas are cleared by burning of the primary marsh forest, which practice leaves the organic material exposed to the climate. As a consequence, increased mineralization of the peat takes place, which results in subsidence of the land surface at an average rate of 10 cm/year. The underlying marine sediments are exposed after 10 to 15 years as was confirmed by the local (immigrant) farmers.

To combat the unwelcome formation of acid sulphate soils in southern Kalimantan and to preserve the agriculturally valuable peat soils, the following measures are essential:

1. The water table should be kept as high as possible, to prevent subsidence of the land surface and further oxidation of pyrites.

2. Canals and water courses should be brought into optimal condition to reduce the area with stagnant water and to improve leaching of soils which presently accumulate noxious substances.

3. Where peat is present, soil management should primarily be directed towards preservation of the organic matter. Adequate water control and covering of the

soil surface could substantially reduce mineralization.

Reclamation

The reclamation of the coastal area of South Kalimantan has been a subject of discussion for several decades. Originally the local population made a start with reclamation by the construction of a large number of hand-dug canals to improve the accessibility of the area and to facilitate the cultivation of swamp rice.

In 1922 reclamation of the coastal swamps drew the attention of the Government. Soil surveys were carried out (Schreuder 1932; Van Wijk 1950) and the Agricultural Extension Service started a controlled system of wet rice cultivation (Schophuys 1936). In 1937 the area became an official transmigration project.

After the second world war, four main reclamation systems were proposed:

- The "controlled drainage" system, proposed by Van Wijk, is based on the traditional marsh rice cultivation under strict supervision of the extension service. In this system the seasonal floodings ("bandjirs") and water stored in thick layers of marsh-forest peat supply the needed irrigation water. Due to the considerable clearance of the marsh-forest this system might not be feasible anymore.

- In 1958 Ir.Pangeran Mohamad Noor launched his "tidal swamp system" of reclamation, which essentially consisted of irrigation at high tides, followed by gravity drainage at low tide. In particular in the backland, where tidal influence is limited, this method gave unsatisfactory results. The rain-dependent inland dries out in pronounced dry seasons, which results in acidification and irreversible subsidence of the land surface.

At present two other systems are still being considered:

- The first system, proposed and partly realized by Schophuys in 1950 and later, is known as the "polder plan". It was devised for application in areas with and without tidal influence and comprises the following main steps:

1. The construction of canals to carry off noxious substances, leached out with irrigation water from the inland.
2. The installation of pumps and automatic valves for irrigation with river water.
3. The installation of automatic valves to control drainage.
4. The intensification of agriculture by the promotion of fertilizer application and by the introduction of plant selection, crop rotation and mechanization.

Where needed, protective measures against seasonal flooding should be taken (see Fig.3).

Prior to any forced change in the present soil/water equilibrium, detailed soil studies are essential. Not only factors of direct importance for designing a system, e.g. permeability, water depth and quality, bearing capacity of the soil, etc., but also other aspects, neglected up to now, should be part of the preparatory studies. The pyrite content of the soil (determinative for present and potential acidification), the location and depth of peat occurrences and the ripening stage of the soil are of decisive importance for the success of any reclamation system.

Undoubtedly properly executed empoldering, which has proved successful all over the world, would solve the area's major problems. Nevertheless the Indonesian Government is hesitant to realize this large scale empoldering project as it regards the construction costs (estimated at $ 250 per hectare) as too high and fears that skilled personnel, required the operate the installations cannot be provided. The government therefore ordered the design of a reclamation system by means of gravity drainage only.

- The Gadjah Mada University of Jogjakarta developed a system grafted on the reclamation methods practised by the Buginese and Bandjarese for generations. Reportedly, laboratory tests gave satisfactory results and at present the system is being tested in the Barambai pilot area, located along the river Barito, some 55 km inland. The basic design of the Gadjah Mada system is given in Fig.4.

A primary channel, perpendicular to the river, splits into 2 secondary channels, that are each terminated by a basin of 300 x 300 x 1½ m. Tertiary channels enable effective penetration of leaching water at high tide. The entrances of the tertiary channels are narrower near the river than deeper inland, to obtain equal discharge of all tertiary channels at low tide. The basins serve as storage reservoirs and increase the amount of outflowing water, thus ensuring efficient discharge of leached products.

From the hydrological viewpoint, installation of irrigation pumps is very desirable, as was agreed by the designer of the system, Prof.Ir.Soenarjo. This, however, is contrary to the instructions given by the Indonesian Government.

At this moment the system has been in operation for only two years and the results obtained are not yet sufficient to allow a final judgement on this system's applicability.

It is the authors' personal opinion that installation of pumps will prove itself inevitable in the long run, as pumping will substantially increase the desired leaching. If complete reclamation - including the land situated in the interior - is persued, a separate system of drainage and irrigation with river water is imperative.

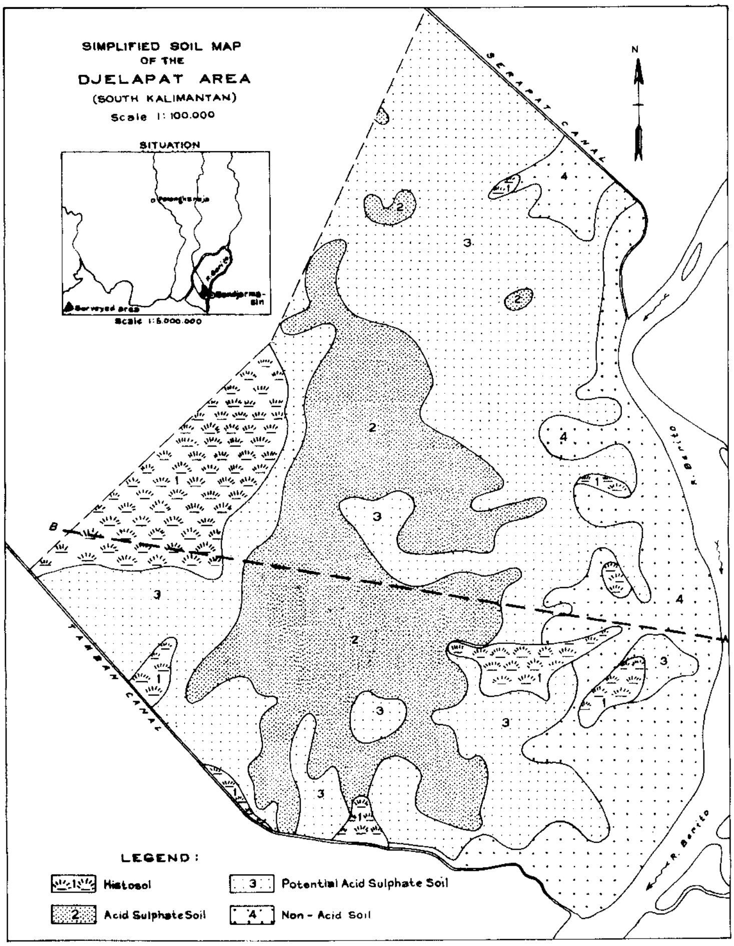
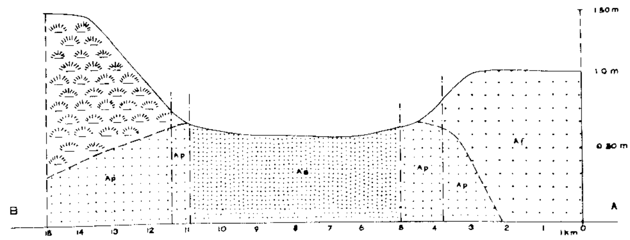


Fig.1. Simplified soil map of the Djelapat Area in the tidal region near Bandjarmasin, South Kalimantan



SOILS :	ORGANIC SOILS	POT. A.S.S. Ap	ACID SULPHATE SOILS As	POT. A.S.S. Ap	NON-ACID SOILS Af
PH :	> 4.5	4.5 - 5.5	< 4.5	4.5 - 5.5	> 5.5
NATURAL DRAINAGE :	POOR	POOR	POOR	MODERATE	EXCELLENT
TIDAL INFLUENCE :	NONE	NONE	NONE	MODERATE	STRONG
LAND USE :	PRIMARY FOREST, CASSAVA, PINE APPLE	MARSH, SAWAH BAJAR	SECONDARY FOREST, MARSH, LOW YIELDING SAWAH	SAWAH BAJAR	ORCHARDS, GARDENS

Fig.2. Schematic cross-section through the Djelapat Area.
For location see Figure 1.

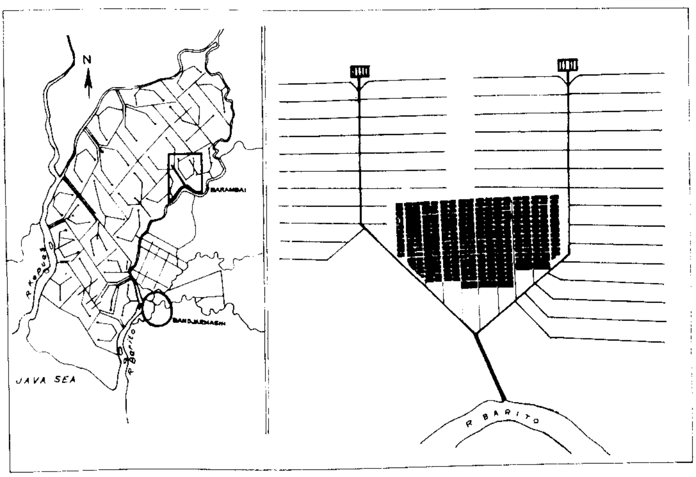


Fig.4. The Gadjah Mada system of reclamation, as laid out in the Barambai pilot area

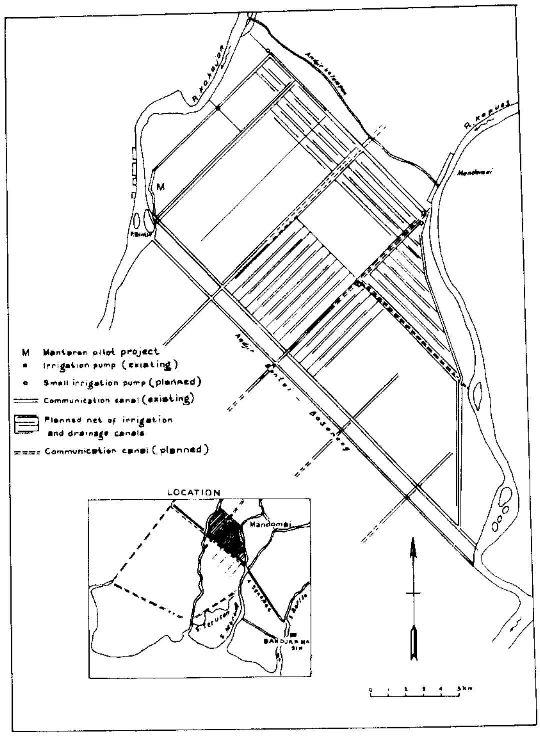


Fig.3. Proposed empoldering in the tidal region near Madomai, Central Kalimantan (after SCHOPHUYS, 1970)

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Summary

The coastal swamps of Borneo consist largely of potential acid sulphate soils. Traditional agricultural practices are adapted to the patterns and properties of soils and hydrological conditions. Hydrological changes and the mineralization of protective peat covers however, are causing the development of actual acid sulphate soils and increased toxicity of surface waters. Two different systems for water control and reclamation on a large scale have been proposed and partly tried out in a pilot scheme. Merits and potential problems of both systems are discussed.

Résumé

Les sols principaux des plaines littoral marécageuses du Bornéo sont des sols sulfatés acide peu développés. L'agriculture traditionelle s'est adaptée assez bien à la repartition et les propriétés des sols et des régimes hydrologiques. Pourtant des changements hydrologiques et la minéralisation des couches tourbeuses protectrices mènent à un développement progressive des sols sulfatés acide et à une toxicité augmentée des eaux de surface. On a proposé deux systèmes pour la régulation de l'eau et la recupération des tierres en grand, et déjà ont a realisé un polder expérimental. Les bénéfices et désavantages rélatives de chacun de ces systèmes sont discutés.

Resumen

Los suelos principales de las llanuras costeras pantanosas del Bórneo son suelos de sulfatos ácidos poco desarrollados. La agricultura tradicional se ha bastante bien a las peculiaridades de los suelos y regímenes hidrológicos. Sin embargo hay cambios hidrológicos y también una reducción de capas turbosas superficiales que conducen a un desarrollo progressivo de los suelos de sulfatos ácidos y una toxicidad alzada de las aguas. Por eso han sido planteado la regulación de agua y la recuperación de tierras al por mayor. Se discute las ventajas y los problemas de dos sistemas de recuperación.

Zusammenfassung

In der Küstenebene Borneos gibt es grosse Flächen mit schwefelsauren Marschböden. Die traditionelle Landwirtschaft ist den Eigentümlichkeiten der örtlichen Boden- und Wasserverhältnisse gut angepasst. Hydrologische Änderungen und stetige Mineralisierung der Torfdecke unterstützen trotzdem die fortschreitende Entwicklung der schwefelsauren Böden und den höheren Gehalt an giftigen Substanzen im Oberflächenwasser. Deswegen erwägt man die Wasserkontrolle und Urbarmachung der Marschen im Grossen. Zwei verschiedene Systeme sind vorgeschlagen und teils auch im Versuchspolder geprüft worden. Vor- und Nachteile beider Systeme werden besprochen.

D I S C U S S I O N

COULTER: Are all soils in the Kalimantan Polder acid sulphate soils?

DRIESSEN: Yes.

COULTER: Under what conditions occurs the subsidence of the peat at a rate of 10 cm per year?

DRIESSEN: In the centres of the depressions the subsidence is most conspicuous. First the forest is burned and casave is grown without special drainage. After 3 or 4 years the peat is drained for pineapple growing. This consumes most of the peat layers in 10-15 years time.

ACIDIFICATION OF MANGROVE SOILS AFTER EMPOLDERING IN LOWER CASAMANCE. EFFECTS OF THE TYPE OF RECLAMATION SYSTEM USED

Gora Beye
Djibelor Rice Research Station
Ziguinchor, Senegal

1. Introduction

It is almost 40 years since research began on the mangrove soils in West Africa and many studies have been undertaken with a view to extending the areas that could be used for rice-growing. The main research has been carried out at Rokupr, on the West African Rice Research Station, Sierra Leone (5, 8, 9, 10, 13, 19, 20a, 20b, 20c, 23), in Gambia (4), and in Nigeria (6, 22). The results may be summed up as follows:

a) From the ecological standpoint (4, 13), five species of mangrove are found on the West African Coast: Laguncularia racemosa (Gaertn.), which is not very common; Avicennia nitida (Jacq.), and three species of Rhizophora: R.racemosa (G.F.W.Mey), R.harrisonii (Leechman), and R.mangle (L.).

b) Empoldering and drying the soils leads to very high acidity and to conditions that are unsuitable for growing rice (20a). This acidification seems to be due to the oxidation of the sulphides, polysulphides, and basic sulphur found in fairly large amounts in these soils (8).

c) A high seasonal variation occurs in the surface pH value and the soils become more acid under Rhizophora vegetation (20b, 20c).

Vieillefon (21), in a study of the mangrove soils in Casamance, Senegal, found extremely low pH values of about 2. The author of a survey (2) of mangrove soils used for rice-growing in Lower Casamance confirms Vieillefon's results and found high average sulphate contents of from 2.5 to 5% of dried earth.

As $CaCO_3$ is almost non-existent in the soils and the absorbent complex is low in Ca and Mg, high acidification may be expected in the mangrove soils in Lower Casamance after empoldering.

After a detailed study and extensive survey of these soils in two polders, the Dutch firm ILACO (12) came to the conclusion that there was no reason to speak of acid sulphate soils in Lower Casamance and the pH for most of the soils could be expected not to drop below 5.

With these differing appraisals and the many types of toxicity caused by the acidity of acid sulphate soils under rice (3), it was thought important to study the evolution of the pH of the mangrove soils in Lower Casamance after empoldering. Compared with previous research, this investigation placed greater emphasis on studying how the type of reclamation system used affects the evolution of the pH.

This paper consists of the results of this study.

2. Site and method of study

The research was carried out in the Medina polder, 16 km south of Ziguinchor, in Lower Casamance, Senegal. It was started in 1965 by ILACO (12), with a view to studying the problems involved in diking the saline valleys in Lower Casamance and the best way to remove the salt. ILACO continued its investigations up until 1967, after which they were carried on by IRAT (French Tropical Agriculture Research Institute) for the Senegal Government.

a) Description of the polder

From the drainage standpoint, the polder (Fig.1), covering a diked area of approximately 10 ha, consists of two parts: gravity drainage through channels fitted with gates: Sections A, B, and H; and drainage by the pumping station in the "pumped section", consisting of the C, D, E, F, and G sub-sections.

The water management system is as follows (12):

Section A: A shallow drainage system with a surrounding ditch 1 m deep. The channel is left open during the rainy season when electrical conductivity is below 4 millimhos/cm at 25 °C. During the dry season it is opened every 5 days on an average to moisten the soil, which must be kept damp.

Section B: Very shallow drainage, with open ditches, dried during the dry season and leached with salt water at the end of the dry season. Water is let in from 1st July to 31st December and kept out from 1st January to 30th June.

Section H: Enclosed by a channel, surrounded by a dike, represents local system, permanently connected to the tidal creek until 1968, since when it has been dried out during the dry season.

Pumped Section: Consisting of 5 sub-sections, with different drain depths and spacings.

Sub-section C: Deep drainage with ditches 1 m deep, and 20 and 40 m apart.

Sub-section D: Deep drainage with ditches 1.5 m deep, and 20 and 40 m apart.

Sub-section E: Deep drainage with ditches 1 m, and 1.5 m deep, 20 m apart.

Sub-section F: Drainage with plastic pipes 0.5 m under the surface, 10 m and 20 m apart.

Sub-section G: Drainage with plastic pipes 1 m below the surface, 10 m and 20 m apart.

In the pumped section, the groundwater level should, in theory, be kept 1.3 m below the surface.

b) Samples and measurements

Soil samples were taken from several places in these different sections and sub-sections, every month for the 0-20 cm horizon, and every 2 months for the 40-60 cm and 80-100 cm horizons. On these samples of air-dried soils, the pH and electrical conductivity were measured. In situ pH measurements were also taken on wet unturned soil with a portable pH meter.

The sampling points were selected according to the water management system, the drainage depth, and the original vegetation before empoldering.

c) Analysis methods

The pH in air-dried soils was measured on a solution of soil/water : 1/2.5. Under ILACO and up until 1968, it was measured by colorimetric determination using the Hellige method, and since then by using a glass electrode in a protective casing with a Ponselle pH meter.

Soil ripeness was estimated in the field using the Pons and Zonneveld method (17), and potential acidity with the van Beers method (1), with H_2O_2 at 30%.

3. Results

Study has been undertaken on the effects produced by the water management system and drainage intensity, the seasonal variation of the pH, acidification on drying, and the effects of the original vegetation on acidification.

a) Influence of the water management system and drainage system

The results of two years' observations and measurements (1968-1969 and 1970-1971) are given in Tables 1 and 2, for the surface layer (0-20 cm).

For the whole of the polder, the highest acidity occurred in Section B and in the pumped section with annual averages of 4.2 and 4.1 respectively for 1968-1969, and 4.3 and 3.8 in 1970-1971. The drop in the annual average pH in Section H, from 5 in 1968-1969 to 3.8 in 1970-1971, is due to a change in the water management system; in fact, since 1969 it has been dried in the dry season.

Section A is the lowest in acid with an average of 5.7 in 1968-1969 and 5.4 in 1970-1971.

The differences in the pH values within the pumped section reflect the differences in drainage intensity; the deeper the drainage, the lower the pH. (Sites C 1 and D 1.) Ditch drainage, which is more effective, causes greater acidification than drainage by plastic pipes. (Sites F 1 and E 1.)

With the same type of drainage, the spacing or depth of the drains may have a considerable effect on the pH, which explains the following pH values, which are averages of samples from several points, given in terms of the drain depth and spacing.

DRAINAGE BY DITCHES	1968-1969	1970-1971
1 m deep, 20 m apart	4.92	4.20
1 m deep, 40 m apart	4.84	3.90
1.5 m deep, 20 m apart	4.03	3.43
1.5 m deep, 40 m apart	3.53	3.30
DRAINAGE BY PLASTIC PIPES		
0.5 m below surface, 10 m apart	4.59	4.20
0.5 m below surface, 20 m apart	4.82	4.55
1 m below surface, 10 m apart	3.95	3.60
1 m below surface, 20 m apart	4.41	3.75

With the same spacing, deeper drainage produces greater soil acidity. In addition, for drainage with plastic pipes at the same depth below the surface, the smaller spacing leads to higher soil acidity; for ditch drainage, the opposite effect is produced.

b) Seasonal variation of the pH

in air-dried soil: Table 3 shows the pH values of air-dried soil from the surface layer (0-20 cm) in July, August, and September (the rainy season) and March, April, and May (the dry season) for the two years studied. The average pH value is seen to fall considerably during the dry season, with the lowest figures found in April. This drop is especially noticeable on the plots with intensive drainage that are dried during the dry season.

Evolution of the in situ pH during the rainy season: Table 4 shows how the pH measured in situ in the 0-20 cm horizon of submerged soil develops over the rainy season. The pH is seen to increase after submersion, which must correspond to soil reduction, and this confirms previous results (15).

Acidification on drying: Table 5 shows how substantially the pH values fall during air-drying. The degree of acidification varies with the water management system and drainage methods. The drop is greater when the pH value of the dried soil is lower, which confirms the results obtained by Ponnamperuma (14).

c) Variations in the pH values of air-dried soil from the 0-20 cm horizon, in terms of the original vegetation

Table 6 gives the data for 1968-1969 and 1970-1971, showing that:

with the same drainage system, vegetation has a very prominent effect: Sites B 1, C 1 and E 1, with Rhizophora vegetation producing the most acid soils;

with the same vegetation, drainage depth has a considerable effect: Sites B 2 and E 1.

4. Discussion

The above-mentioned results agree with those obtained by many authors in reports on the reclamation of mangrove soils throughout the world and particularly in West Africa (16, 24, 1, 5, 7, 8, 10, 11, etc.). Before drainage and empoldering, the soils are under anaerobic conditions. In this reducing environment, which is high in easily decomposable organic matter, in sulphates from sea water, and in free iron, both the reduction of the sulphates by sulphate reducing bacteria and the precipitation of iron monosulphides and polysulphides are particularly intense (24). The reactions that occur may be expressed as follows, with CH_2O representing the source of the organic matter:

$$4Fe(OH)_3 + 4CaSO_4 + 9CH_2O = 4FeS + 4Ca(HCO_3)_2 + CO_2 + 11\ H_2O$$

The sediment is turned black by the FeS. In time, the polysulphides are produced under the reaction:

$$FeS + S = FeS_2$$

With empoldering, exclusion of salt water, and drainage, the soil comes into contact with the air and the sulphides are oxidized. This oxidation phase may be summed up as follows (3):

1. $FeS_2 + H_2O + 3\ 1/2\ O_2 = FeSO_4 + H_2SO_4$

2. $2FeSO_4 + 1/2\ O_2 + H_2SO_4 \xrightarrow{\text{Thiobacillus ferrooxidans}} Fe_2(SO_4)_3 + H_2O$

3. $Fe_2(SO_4)_3 + FeS_2 = FeSO_4 + 2S$

4. $S + 1/2\ O_2 + H_2O \xrightarrow{\text{Thiobacillus thioxidans}} H_2SO_4$

5. $Fe_2(SO_4)_3 + 2H_2O = 2Fe(OH)(SO_4) + H_2SO_4$

6. $Fe_2(SO_4)_3 + 6H_2O = 2Fe(OH)_3 + H_2SO_4$

Oxidation is particularly intense with a soil moisture content of between 40% and 10% (9, 10). These values occur in the plots drained by pumping and gravity during the dry season. With deeper and more intensive drainage the soil comes into greater contact with the air, and oxidation and acidification are therefore higher. This explains why drainage by plastic pipes, which is not as effective as by ditches, produces less acidity, and why the soil in Section A, which is constantly wet and under more or less anaerobic conditions, retains a relatively high pH.

The process is exactly the same when a sample of wet soil is dried.

The products of the oxidation of the soil sulphides react on the carbonates, silicates, exchangeable bases, and green minerals in the soil (18). The final soil acidity is a balance in the sediment between the acidifying capacity of the sulphides and the neutralizing capacity of the carbonates, silicates, exchangeable bases and green minerals. In Lower Casamance, this buffer effect is extremely low due to the lack of carbonate and the laterite drainage basin.

The results in Table 7, with the N values (Pons and Zonneveld) (17) for measuring the van Beers potential acidity (1) and soil ripeness, confirm the afore-mentioned explanation. They show that with intensive drainage, the surface soil has reached full ripeness and maximum acidity, whereas for the others, the soil is still ripening and acidification is not yet complete. Final acidity has not yet been reached at the depth where the soil is still under anaerobic conditions, with the characteristic dark grey colour of FeS (7.5 YR 4/0).

The drop in the pH in the surface soil during the dry season is due both to higher oxidation with an accumulation of sulphates (unpublished results) and to the upward capillary movement of the acid products to the surface (18, 20c).

An increase in the pH after submersion in the rainy season has been reported several times by Ponnamperuma (14, 15). This is due to the reduction of the soil and the ensuing transformation of ferric iron into ferrous iron, as in the following equation:

$$Fe(OH)_3 + e = Fe_2 + 3OH$$

Many authors have shown that the soils under Rhizophora vegetation or fibrous mangrove soils have the highest acidity after drying (10, 20b, 5, 7). This phenomenon is mainly due to the fact that the reduction of sulphates to sulphides by sulphate reducing bacteria requires a reducing environment rich in easily decomposable organic matter such as Rhizophora radicels (23). The most suitable conditions for producing ferrous monosulphides and polysulphides are therefore found under Rhizophora vegetation, which accounts for their high accumulation and high acidity after draining and drying.

5. Conclusion and summary

The evolution of the surface pH value in Lower Casamance mangrove soils has been studied in the Medina polder. The author has placed the emphasis on how it is affected by the water management system, the depth and spacing of the drains, and the original vegetation before empoldering. The main results may be summed up as follows.

The mangrove soils in Lower Casamance are acid sulphate soils (cat clays) or potential acid sulphate soils (mud clays) which become very acid after drying out. Under deep intensive drainage, acidification is very fast. When dried out completely during the dry season, the soils become highly acid and ripen very quickly.

Soils under Rhizophora vegetation or rich in easily decomposable organic matter are the most liable to acidification after drying.

High acidity may be avoided by using a water management system which keeps the soils constantly wet, but then they ripen more slowly. From this viewpoint, the dam sluice-gate system might make it possible to reclaim mangrove soils without much risk of acidification.

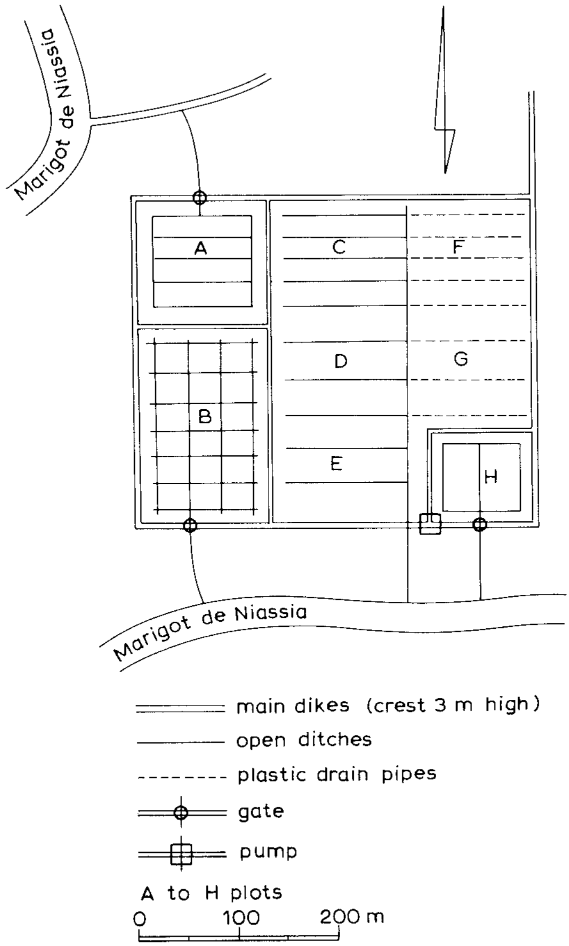

Fig.1. Medina polder

TABLE 1. pH OF AIR-DRIED SOIL IN SURFACE LAYER (0-20 cm). 1968-1969

Plots sampled	1968 Jul.	Aug.	Sep.	Oct.	Nov.	Dec.	1969 Jan.	Feb.	Mar.	Apr.	May	June	Annual averages
A 1	5.2	5.4	6.2	5.2	5.9	5.7	5.7	5.3	6.1	5.8	6.2	6.4	5.7
B 1	4.6	3.8	4.2	4.1	4.2	4.4	4.5	3.8	4.5	3.9	4.3	4.5	4.2
C 1	4.6	4.6	4.6	4.4	4.6	4.5	4.4	4.2	4.8	4.5	5.0	5.5	4.4
D 1	4.8	3.9	4.7	3.7	3.6	3.8	3.9	3.5	4.2	3.8	4.0	4.0	3.9
E 1	4.0	3.1	3.2	2.9	3.1	3.1	3.1	3.0	3.6	3.4	3.8	4.0	3.3
F 1	5.4	5.0	4.8	4.9	4.7	4.1	4.3	4.1	5.2	4.9	5.5	5.5	4.8
H 1	5.2	5.4	5.4	5.0	5.5	5.0	4.9	4.4	5.5	4.2	4.6	4.9	5.0

TABLE 2. pH of AIR-DRIED SOIL IN SURFACE LAYER (0-20 cm). 1970-1971

Plots sampled	1970 Jul.	Aug.	Sep.	Oct.	Nov.	Dec.	1971 Jan.	Feb.	Mar.	Apr.	May	June	Annual averages
A 1	5.4	5.2	5.1	5.4	5.7	5.3	5.5	5.4	5.4	5.8	5.2	6.3	5.4
B 1	4.1	4.0	3.8	4.3	4.8	4.4	3.4	5.1	4.5	4.0	4.9	4.9	4.3
C 1	4.2	4.0	4.5	4.6	4.6	4.7	3.5	4.0	3.7	4.0	3.8	4.2	4.1
D 1	3.4	3.2	3.1	3.0	3.4	3.5	3.9	3.2	3.5	3.6	3.2	3.5	3.4
E 1	3.5	3.3	3.2	3.3	3.3	3.8	3.1	3.0	2.9	3.0	2.8	3.1	3.2
F 1	5.0	4.7	4.5	4.9	4.6	4.6	4.5	4.4	4.5	4.3	4.4	4.8	4.6
H 1	3.9	3.3	3.2	3.4	5.0	4.4	4.4	3.7	4.6	3.5	2.7	3.7	3.8

TABLE 3. SEASONAL VARIATIONS IN THE pH OF AIR-DRIED SOIL IN THE SURFACE LAYER (0-20 cm)

Sampling point	1968 - 1969 rainy season Jul.	Aug.	Sept.	dry season Mar.	Apr.	May	1970 - 1971 rainy season Jul.	Aug.	Sept.	dry season Mar.	Apr.	May
A 1	5.2	5.4	6.4	6.0	5.8	6.2	5.4	5.2	5.1	5.4	5.8	5.2
B 1	4.6	3.8	4.2	4.5	3.9	4.3	4.1	4.0	3.8	4.5	4.0	4.9
C 1	4.6	4.6	4.7	4.8	3.3	5.0	4.2	4.0	4.5	3.7	4.0	3.8
D 1	4.8	3.9	4.8	4.3	3.8	4.0	3.4	3.2	3.1	3.5	3.6	3.2
F 1	5.4	5.0	5.0	5.2	5.0	5.5	5.0	4.7	4.5	4.5	4.3	4.4
H 1	5.2	5.4	5.6	5.6	4.4	4.6	3.9	3.3	3.2	4.6	3.5	2.7

TABLE 4. VARIATIONS IN THE pH UNDER SUBMERSION DURING THE RAINY SEASON (pH MEASURED IN SITU) IN THE SURFACE LAYER (0-20 cm)

Sampling point	July	August	October
A 1	4.0	5.7	5.7
B 1	3.6	4.4	5.0
B 2	3.6	4.3	5.3
C 1	4.6	4.5	4.1
D 1	3.8	4.5	3.4
E 1	3.7	3.8	3.0
F 2	4.4	5.7	4.2
H 2	3.8	5.2	5.7

TABLE 5. SOIL ACIDIFICATION ON DRYING. SURFACE LAYER (0-20 cm)

Sampling point	pH in situ (under wet conditions)	pH after drying (1/2.5)	drop in the pH
A	6.22	5.85	0.37
B	5.68	4.26	1.42
H	6.03	4.77	1.26
D	5.99	4.91	1.08
D	5.79	4.01	1.78
E	5.14	3.58	1.56
F	6.64	4.96	1.68
G	6.51	4.32	2.19

TABLE 6. VARIATIONS IN THE pH VALUES OF AIR-DRIED SOIL FROM THE 0-20 cm HORIZON, IN TERMS OF THE ORIGINAL VEGETATION

Sampling point and vegetation	1968-1969			1970-1971		
	Feb.	Apr.	Aug.	Feb.	Apr.	Aug.
A 1 (Heleocharis caribea)	5.9	5.4	5.2	5.3	5.8	5.7
B 1 (Scirpus littoralis)	4.2	4.2	3.8	4.0	3.9	4.1
B 2 (Rhizophora racemosa)	4.6	3.4	3.5	3.5	4.1	4.6
C 1 (Scirpus *littoralis* & Philoxerus vermicularis)	4.8	4.4	4.6	4.1	4.6	4.9
E 1 (Rhizophora racemosa)	3.5	3.2	3.1	3.0	3.5	3.6
F 2 Tanne (without vegetation)	4.8	4.5	4.8	4.0	4.8	4.8
H 2 (Avicennia nitida)	5.4	4.9	5.1	4.1	4.0	4.2

TABLE 7. SOIL RIPENING AND MAXIMUM POTENTIAL ACIDITY

Plots sampled	Soil ripeness in N+) 0-20 cm	pH++) after adding H_2O_2 at 30%		
		0-20 cm	40-60 cm	80-100 cm
A 2	0.80 almost ripe	2.0	1.0	1.0
B 2	0.44 very ripe	4.0	4.0	1.0
C 1	0.62 ripe	5.0	4.0	3.0
D 1	0.45 very ripe	3.0	3.0	1.0
E 1	1.10 half ripe	3.5	2.0	1.0
F 2	0.77 almost ripe	5.0	3.5	2.5
H 2	1.17 half ripe	3.0	2.0	1.0

+) N is given by the formula:

$$N = \frac{A - 0.2\ (100-L-H)}{L + 3H}$$

N = water content, the standard value of physical development that is the amount of water in grams absorbed by 1 g of the clay fraction

$$A = \frac{100 \times W\%}{100 - W\%}$$ W = water content of the soil in % of wet soil

L = clay content (less than 2 microns)

H = organic matter content

++) The pH is determined in the field using a pH indicator paper (Merck)

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Summary

In an experimental polder the evolution of surface pH-values of acid sulphate soils was studied in relation to water management systems, depth and spacing of drains, original vegetation and ripening.

RRésumé

Dans un polder experimental l'évolution du pH de la couche superficielle des sols sulfatés acides, a été étudiée en fonction des systèmes de contrôle d'eaux, la profondeur du drainage et l'écartement des drains, la végétation originelle et la maturité des sols.

Resumen

En un pôlder experimental se ha estudiado la evolución del pH en la capa superficial de suelos de sulfatos ácidos en relación de los sistemas de control del agua, la profundidad y el intervalo de las zanjas o tubos de drenaje, la vegetación de origen, y la madurez de los suelos.

Zusammenfassung

In einem Versuchspolder wurde die Entwicklung der pH-Werte in der oberen Schicht schwefelsaurer Böden studiert im Zusammenhang mit den Wasserkontrolle-Systemen. Es sind auch die Tiefe der Entwässerungsgräben, Abstand der Entwässerungsröhren, ursprüngliche Vegetation und Reifungsgrad der Böden behandelt.